NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

Holographic Interferometry of The Flow Field Between a Fin And Flat Plate

by

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March 1972

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Holographic Interferometry of The Flow Field Between a Fin And Flat Plate

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; (March 1972)

5. AUTHOR(S) (First name, middle initial, last name)

Robert Ward Heyer

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1972	178	27

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

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The factors which are thought to have limited the success of the experiment include vibration of the model, fluctuations of the tunnel flow and the fact that the model was somewhat too large in relation to the size of the wind tunnel test section. Schlieren photography was used to look through and around the model and to verify that the same flow was established as was reported by Thomas [23, 24] and Winkelmann [26, 27].

The data reduction of holographic interferograms was, for the first time, accomplished using photographic enlargements. This technique is considered to be much easier and more accurate than the one used in the previous investigations. However, the data reduction step, because of the time and labor involved, is considered to be the rate controlling process of the whole analysis.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
fin-flat plate flow field						
wing-root flow field						
holography						
three-dimensional density field						
three-dimensional flow field						
fin						
flat plate						
interferogram						
flow field						
fin flat plate junction						
wing root junction						
holographic interferometry						
supersonic flow						

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

UNCLASSIFIED
Security Classification

A-31409

Holographic Interferometry of The Flow

Field Between a Fin And Flat Plate

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1972

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The data reduction of holographic interferograms was, for the first time, accomplished using photographic enlargements. This technique is considered to be much easier and more accurate than the one used in the previous investigations. However, the data reduction step, because of the time and labor involved, is considered to be the rate controlling process of the whole analysis.

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ACKNOWLEDGEMENTS

This writer wishes to gratefully acknowledge Dr. D. J. Collins for his most valuable guidance and assistance during the course of this investigation; Dr. T. H. Gawain for his valuable assistance and recommendations in the writing of this report; the technical staff of the Department of Aeronautics under R. Besel and T. Dunton, particularly N. Lechenby, J. Multon, and G. Middleton, for their able assistance in the fabrication and assembly of the models and equipment used in this study; Mrs. John B. Coleman Jr. for her considerable effort in the final preparation; and my wife and family for their noble patience and encouragement.

I. INTRODUCTION

The determination of the flow field in the wing-body junction of an aircraft in supersonic flight presents many problems. The typical approach has been to measure the static pressure on the surface using many small pressure taps [23, 24] and to determine the velocity field in the junction using translatable pressure probes [18, 19, 25]. Thomas [[illegible], 24] and Winkelmann [26, 27] used azobenzene and oil-smear tests to view the flow field around a flat plate-fin junction. From the streak patterns on the plate and fin, they were able to illustrate the three-dimensional flow field, although in a partially speculative fashion. This study has attempted to map the density field in a fin-flat plate junction three-dimensionally using holographic interferometry. Although this objective was not fully achieved, the feasibility of the method has been demonstrated.

By using a Q-switched laser with exposure times of about twenty nanoseconds, it was possible to obtain three-dimensional holographic interferograms of the density field in the fin-flat plate junction. From holograms taken at a number of viewing angles the fringe shifts in different planes could be obtained. By integrating this information using a FORTRAN computer program, the density field can be determined. This technique has been previously demonstrated for the flow field of a free jet by Matulka [12, 13] and for the supersonic flow field around a cone at angle of attack by Jagota [3, 4].

The tests were performed at the Naval Postgraduate School, using the four-inch supersonic wind tunnel.

II. EXPERIMENTAL APPARATUS

A. THE WIND TUNNEL

The investigation was conducted in the Naval Postgraduate School blowdown-to-atmosphere supersonic wind tunnel. The test section is four inches by four inches in cross section and six inches long with two different sets of side walls. The two-inch thick plexiglas side walls, which have a refraction index of 1.49, present a complete field of view of the flow from the nozzle throat to aft of the test section mounting bracket (Figure 1 (a)). The second set of sidewalls used are aluminum with high quality optical glass portholes located in the test section area (Figure 1 (b)). The interchangeable nozzle for a test section Mach number of 2.8 was used for all tests. The nominal run time is five minutes at Mach 2.8 with the maximum stagnation pressure of about 105 pounds per square inch.

B. THE HOLOGRAPHIC ARRANGEMENT

The holographic arrangement is illustrated in Figure 2 and shown in photographs included as Figures 3, 4, and 5. The equipment stand was rested on a portion of the building floor that was vibrationally isolated. A Konrad K-1 pulsed ruby laser with a Pockels cell Q-switching unit was used to produce monochromatic light at a wave length of 6943 Angstroms and exposure time of twenty nano-seconds. The laser cavity length was seventy-three cm. giving a coherence length of about ten cm. To maintain the laser head and output etalon at a constant temperature of 27.5 degrees centigrade, a Lauda constant temperature circulator Model N was used. This was controlled by an electronic relay type R-10 coupled with a Culligan de-ionizer.

Holograms were obtained by routing the reference beam under the wind tunnel and the scene beam through the test section, and intersecting the two beams on the hologram plate at an intersecting angle of approximately 50 degrees. The beam sizes were controlled by translating the concave lenses located between the beam splitter and hologram plate in each beam (Figure 2). The Q-switched laser and optics were aligned using a continuous wave helium-neon laser. For reference purposes, grids were mounted on the outside tunnel walls and aligned using a surveyor's transit. The holographic stand and test section were completely enclosed in a wooden box to enable holograms to be taken in the daylight (Figure 6).

C. THE WIND TUNNEL MODELS

The fin-flat plate models used are shown in Figures 7 (a), (b), (c), and (d). The metal portions of both models were stainless steel. The center section, part of one strake, and all of the other strake of the first model in Figure 7 (a) were made of epoxy while the center section of the second model, Figures 7 (b) and 7 (c), was fabricated from plexiglas. The flat plate grids in both models were etched into the plastic surface and coated with a clear plastic to achieve a smooth surface.

The models were rotated about their sting mounts as shown in Figure 7 (d). Alignment for the desired rotation angle was accomplished by aligning prescribed lines on the sting mount collar with a scribed mark on the sting stand using a surveyor's transit.

III. ANALYTICAL EVALUATION OF THE DENSITY FIELD

A. THE BASIC INTERFEROMETRIC EQUATION

Interferograms are created when two coherent light beams are superimposed on each other and projected on a viewing screen. The light and dark regions observed correspond to the relative phase difference between the two beams which are caused by a difference in the two optical path lengths. Consider a coherent beam which is split and then recombined on a viewing screen. A difference in optical path lengths of the two beams may be achieved in two ways in order to create an interferogram. The first is to make the physical distance traveled by the two beams different. In a vacuum this path length difference is expressed as $L = C_0 \Delta t$ where C_0 is the speed of light in a vacuum. The second way is to maintain equal physical path lengths but to have the beams traverse through different media prior to recombining. In this case each light beam will travel at a speed $\frac{C_0}{n}$ where n is the index of refraction for the medium traversed. The optical path length difference then becomes:

$$\Delta L = L\,(n_2 - n_1) = C_0 \Delta t \tag{1}$$

The interference pattern or fringes observed may be expressed as a function of the optical path length difference or

$$g = \frac{\Delta L}{\lambda} \tag{2}$$

where: g = fringe shift

λ = wave length of the light source

ΔL = change in optical path

Combining equations (1) and (2), the fringe shift is then

$$g = \frac{L}{\lambda}(n_2 - n_1) \tag{3}$$

The index of refraction is known to be a function of density. Since the speed of light is only slightly less in gases than in a vacuum, the index of refraction could be closely approximated by the series expansion [8]

$$n = 1 + \beta \frac{\rho}{\rho_s} \tag{4}$$

where

β = dimensionless constant related to the Gladstone-Dale constant by $K = \beta/\rho_s$

ρ_s = reference density of 0° C, 760 mm. Hg.

The variation of   with wavelength is small and has a value of 0.000292 for λ = 5893 angstroms.

Considering a fixed difference in the index of refraction between the two beams in Equation (3), then

$$g = \beta \frac{L}{\lambda}\left(\frac{\rho_2 - \rho_\infty}{\rho_s}\right) \tag{5}$$

If the density varies in a beam path, the net change in the optical path length will be the integrated effect along the beam path or

$$g = \frac{\beta}{\lambda \rho_s} \int_0^L (\rho - \rho_\infty) ds = Q \int_0^L f(x,y,z_c) ds \tag{6}$$

where

$$Q = \frac{\beta \rho_\infty}{\lambda \rho_s} \tag{6a}$$

$$f(x,y,z_c) = \frac{\rho(x,y\,z_c)}{\rho_\infty} - 1 \tag{6b}$$

z_c = a plane of constant Z

ds = incremental distance along the ray

In order to determine the density along the beam path where the fringe shift is known from an interferogram, Equation (6) must be inverted.

B. THE INTEGRAL INVERSION

The integral inversion technique was first reported by C. D. Maldonado et al in 1965 [9, 10, 11]. R.D. Matulka [12, 13] and R. C. Jagota [3, 4] used this method to determine the density variation in an asymmetric free jet and about a cone at angle of attack, respectively. The technique involves representing the function, $f(x,y,z_c)$ in Equation (6) by a complete set of orthogonal functions where the unknown coefficients are evaluated using the orthogonality relationship between the set of functions. The functions are orthogonal over the entire plane and also have the propery of being invariant in form to any rotation of the coordinate system. Figure 8 illustrates the coordinate system for the inversion where x and y are the fixed laboratory coordinates and x' and y' are the coordinates in which the fringe number function is defined. As the view through the test section is varied the primed coordinates are rotated with respect to the fixed coordinates x and y.

The fringe shift expressed in Equation (6) may be written as the transform

$$g(\xi, y, z_c) = f(x,y,z_c) \tag{7}$$

or, inverting the equation, the density function, f, is equal to:

$$f(x, y, z_c) = T^{-1} g(\xi, y, z_c) \tag{8}$$

The density function can be expanded in the following manner using a set of polynomial functions, $U^{\pm m}_{m+2k}(\alpha x, \alpha y)$, and unknown complies coefficients, $C^{\pm m}_{m+2k}(\alpha)$

$$f(x,y,z_c) = \sum_{m=0}^{\infty}\sum_{k=0}^{\infty} \epsilon_m \left[C^{m}_{m+2k}(\alpha) U^{m}_{m+2k}(\alpha x, \alpha y) + C^{-m}_{m+2k}(\alpha) U^{-m}_{m+2k}(\alpha x, \alpha y) \right] \cdot e^{-(\alpha^2 x^2 + \alpha^2 y^2)} \tag{9}$$

where $\epsilon_m = \begin{cases} 1/2 & m=0 \\ 1 & m=1,2,3,\cdots \end{cases}$

α = arbitrary scale factor

The polynomial functions, $U^{\pm m}_{m+2k}(\alpha x, \alpha y)$, are invariant in form to a rotation of the coordinate system [10, 12, 13]. They also have a Gauss transform which makes them adaptable to the physical situation and to manipulating into the form of Equation (7). The functions are defined as:

$$U^{\pm m}_{m+2k}(\alpha x, \alpha y) = (-1)^k \alpha \left[\frac{k!\,(\alpha^2 x^2 + \alpha^2 y^2)^m}{\pi (m+k)!} \right]^{\frac{1}{2}} e^{\pm i m \phi} L^m_k(\alpha^2 x^2 + \alpha^2 y^2) \tag{10}$$

where $\phi = \tan^{-1}\left(\frac{y}{x}\right) - \frac{\pi}{2}$ (10a)

L^m_k = Laguerre polynomial

$$= \sum_{s=0}^{k} \left[\frac{(m+k)!}{(k-s)!\,(m-s)!\,s!} \right] \left[(-1)(\alpha^2 x^2 + \alpha^2 y^2) \right]^s \tag{10b}$$

And the Gauss Transform of $U^{\pm m}_{m+2k}$ is:

$$I^{\pm m}_{m+2k}(\alpha y'; \xi) = \int_{-\infty}^{\infty} U^{\pm m}_{m+2k}(\alpha x, \alpha y) e^{-\alpha^2 x'^2} dx' = \frac{e^{\pm i m \xi} H_{m+2k}(\alpha y')}{[k!\,(m+k)!]^{\frac{1}{2}}\, 2^{m+2k}} \tag{11}$$

where $H_{m+2k}(\alpha y')$ = Hermite polynomials

By applying the transform above to Equation (9), the fringe function in

Equation (7) can be written as:

$$g(\xi,y,z_c)=\sum_{m=0}^{\infty}\sum_{k=0}^{\infty}\frac{\epsilon_m\left[C^{m}_{m+2k}(\alpha)e^{im\xi}+C^{-m}_{m+2k}(\alpha)e^{-im\xi}\right]H_{m+2k}(\alpha)e^{-\alpha^2y^2}}{\left[k!(m+k)!\,2^{2(m+k)}\right]^{1/2}} \tag{12}$$

using the following orthogonality relationship on Equation (12)

$$\int_{-\pi}^{\pi}e^{\pm im\xi}e^{\mp in\xi}d\xi\int_{-\infty}^{\infty}H_{m+2k}(\alpha y')H_{n+2\ell}(\alpha y')e^{-\alpha^2y^2}dy'=$$

$$\frac{2\pi^{3/2}}{\alpha}\left[(m+2k)!(n+2\ell)!\,2^{m+2k}2^{n+2\ell}\,\delta_{mn}\,\delta_{(m+2k)(n+2\ell)}\right] \tag{13}$$

where δ is the kroneker delta, the expansion coefficients $C^{\pm m}_{m+2k}$,

can be determined by:

$$C^{\pm m}_{m+2k}(\alpha)=\frac{\alpha}{2\pi^{3/2}}\left[\frac{(k!(m+k)!)^{1/2}}{(m+2k)!}\right]\int\int_{-\pi}^{\pi}g(y',\xi,z_c)H_{m+2k}(\alpha y')e^{\mp im\xi}dy'd\xi \tag{14}$$

Substitution of the coefficients in Equation (14) bact into Equation (9) results in the density variation being expressed as:

$$f(x,y,z_c)=\left(\frac{\alpha}{\pi}\right)^2\sum_{m=0}^{\infty}\sum_{k=0}^{\infty}\epsilon_m\left[k!(m+k)!\right]^{\frac{1}{2}}e^{-(\alpha^2x^2+\alpha^2y^2)}\,\cdot$$

$$\text{REAL}\left[\int_{-\pi}^{\pi}\int_{-\infty}^{\infty}g(y',\xi,z_c)e^{-im\xi}H_{m+2k}(\alpha y')dy'd\xi\right]U^{m}_{m+2k}(\alpha x,\alpha y) \tag{15}$$

or by inserting Equation (10):

$$f(x,y,z_c)=\left(\frac{\alpha}{\pi}\right)^2\sum_{m=0}^{\infty}\sum_{k=0}^{\infty}\epsilon_m\frac{(-1)^k k!}{(m+2k)!}(\alpha^2x^2+\alpha^2y^2)^{m/2}L^m_k(\alpha^2x^2+\alpha^2y^2)\,\cdot$$

$$\left[B^m_{m+2k}(\alpha)\cos(m\phi)+D^m_{m+2k}(\alpha)\sin(m\phi)\right]e^{-(\alpha^2x^2+\alpha^2y^2)} \tag{16}$$

where:

$$B^m_{m+2k}(\alpha)=\int_{-\pi}^{\pi}\int_{-\infty}^{\infty}g(y',\xi,z_c)\cos(m\xi)H_{m+2k}(\alpha y')dy'd\xi \tag{17}$$

$$D^m_{m+2k}(\alpha)=\int_{-\pi}^{\pi}\int_{-\infty}^{\infty}g(y',\xi,z_c)\sin(m\xi)H_{m+2k}(\alpha y')dy'd\xi \tag{18}$$

Equations (16), (17), and (18) are the basic equations used to calculate the density distribution from the experimentally determined fringe variations.

C. THE NUMERICAL PROCEDURE

The form of the density distribution in Equations (16), (17), and (18) must be modified in order to input the experimentally determined fringe distribution. First from Figure 8 and Equation (6b) it can be seen that it is only necessary to integrate Equations (17) and (18) over an area where the density is changing from a known density, ρ_∞ . Outside of this region where there is no change in density, the function $f(x,y,z_0) = 0$, i.e. outside the test section. Also since the fringe distribution is taken in small increments over the test area the coefficients, B and D, can be approximated as

$$B^m_{m+2k}(\alpha) = \sum_{i=1}^{I-1}\sum_{j=0}^{J-1} g(\xi_j+\Delta\xi_j, x_i+\Delta x_i)\int_{\xi_j}^{\xi_{j+1}}\cos(m\xi)\,d\xi\int_{x_i}^{x_{i+1}} H_{m+2k}(\alpha x)\,dx \tag{19}$$

$$D^m_{m+2k}(\alpha) = \sum_{i=1}^{I-1}\sum_{j=0}^{J-1} g(\xi_j+\Delta\xi_j, x_i+\Delta x_i)\int_{\xi_j}^{\xi_{j+1}}\sin(m\xi)\,d\xi\int_{x_i}^{x_{i+1}} H_{m+2k}(\alpha x)\,dx \tag{20}$$

The integral of ξ is easily determined and by using the derivative formula for Hermite polynomials the integral of x may be manipulated to yield

$$B^m_{m+2k}(\alpha) = \left[\frac{1}{2\alpha m}\,\frac{1}{(m+2k+1)}\right]\sum_{i=0}^{I-1}\sum_{j=0}^{J-1} g(\xi_j+\Delta\xi_j, x_i+\Delta x_i)\,\cdot$$
$$\left[\sin(m\xi_{j+1})-\sin(m\xi_j)\right]\left[H_{m+2k+1}(\alpha x_{i+1})-H_{m+2k+1}(\alpha x_i)\right] \tag{21}$$

$$D^m_{m+2k}(\alpha) = -\left[\frac{1}{2\alpha m(m+2k+1)}\right]\sum_{i=0}^{I-1}\sum_{j=0}^{J-1} g(\xi_j+\Delta\xi_j, x_i+\Delta x_i)\,\cdot \tag{22}$$
$$\left[\cos(m\xi_{j+1})-\cos(m\xi_j)\right]\left[H_{m+2k+1}(\alpha x_{i+1})-H_{m+2k+1}(\alpha x_i)\right]$$

In the computation of the density function from Equation (16), obtaining the infinite summations experimentally is not plausible or

possible. It has been demonstrated that by using a finite number of terms and by adjusting the values of $\Delta \xi$, Δ x and α, it is possible to obtain the density distribution with very good accuracy [3, 4, 12, 13]. Equation (16) then becomes:

$$f(x,y,z_0) = \left(\frac{\alpha}{\pi}\right)^2 \sum_{k=0}^{K} \sum_{m=0}^{M} \epsilon_m (-1)^k \left[\frac{k!}{(m+2k)!}\right] (\alpha^2 x^2 + \alpha^2 y^2) \cdot$$

$$L_k^m(\alpha^2 x^2 + \alpha^2 y^2)\left[B_{m+2k}^m(\alpha)\cos(m\phi) + D_{m+2k}^m(\alpha)\sin(m\phi)\right] \cdot e^{-(\alpha^2 x^2 + \alpha^2 y^2)} \qquad (23)$$

IV. EXPERIMENTAL PROCEDURE

A. LABORATORY TECHNIQUES

The analysis of a free jet by Matulka [12, 13] illustrated how holographic interferometry can be used to obtain a complete three dimensional plot of the density within a moving transparent flow field. Jagota [3, 4] in his study of a cone at angle of attack in supersonic flow went one step further by introducing an opaque object into an assumed steady state flow field and describing the density field three-dimensionally.

This investigation has attempted to determine the three-dimensional density field around a transparent object in a supersonic flow field by passing a light beam through the object. Specifically the interest was to describe the flow field existing in the junction of a fin-root intersection.

1. Model Considerations

In order to obtain uniform flow around the fin-root area, a model of the form shown in Figure 9 was selected. The flat plate has a knife

edge and is intended to remain at zero degrees angle of attack so as to establish the flow conditions illustrated. The fin edges were made circular in order to approach flow conditions similar to those established in Winkelmann's [26, 27] investigation. Plastic and metal strakes were added on the model sides so as to maintain two-dimensional flow as well as to add strength to the flat plate. In the first model constructed (Figure 7(a)), maximum visibility of the plastic fin-flat plate center section was achieved by bolting the leading edge and aft plate together through the plastic center section. Due to model flexure, this design was found to be unsuitable and the second model in Figures 7(b) and 7(c) was constructed. The model was made from a single piece of stainless steel. The model rigidity was satisfactory but unfortunately the strengthening borders around the plastic center section reduced the holographic visibility somewhat.

Since the wind tunnel blocks were fixed, it was possible to make multiple test runs with the same flow conditions over the model provided supersonic flow had been established over the model.

2. Holographic Techniques

In order to obtain holographic interferograms it was necessary to ensure that the optical path lengths of the scene and reference beams remained approximately equal. Since the ruby laser is believed to have a coherency length of approximately ten centimeters, the equality of lengths is far less critical than in the classical Mach-Zehner interferometric approach. Consequently a string was used in the experiment to trace the reference beam and then adjust the scene beam. This method kept the two beam lengths within one centimeter of each other. Since the scene beam traversed approximately 4.5 inches of plastic tunnel walls and

grids which the reference beam did not, it was necessary to compensate by making the scene beam physically 2.25 inches shorter than the reference beam. The reference beam varied in length from 61 inches to 68 inches during the experimentation.

To determine the fringe/density field, finite fringe interferograms were made by three different techniques. In the direct fin-root flow approach the diffuser plate was part of the model. Either the mirror, M_5, in Figure 2 or the hologram plate holder was translated between the no-flow exposure and the flow-established exposure. In the total model flow method the diffuser plate was located between scene beam lens, L_3, and the test section (See Figure 2) and it was translated horizontally or vertically. Translations were varied from .001 inches to .006 inches with the translation distance of .003 inches yielding the best fringe separation.

Most of the holograms taken using basically the holographic arrangement shown in Figure 2 gave well-defined fringe patterns. In order to improve upon the fringe definition, a variety of techniques was attempted. The transverse mode selector was varied from 1.0 mm. to 2.5 mm. in increments of 0.5 mm. to determine the best lighting of the model. The hologram plate holder was rotated horizontally to various positions. These positions varied between being perpendicular to the scene beam to being perpendicular to the bisection of the angle between the scene and reference beams. Polarization plates were added in both the scene and reference beams between the test section and hologram plate in the scene beam and between the last mirror, M_4, and the hologram plate in the reference beam. A one-quarter wave plate was also placed between the first lens, L_1, and the beam splitter as recommended by Okayama and Emori [14].

The holograms were taken using 4" x 5" Agfa-Gavaert 8E-75 hologram plates. The developing process involved:

1. Five minutes in Kodak D-19 developer
2. Thirty seconds in an acetic acid stop bath
3. Five minutes in standard fixer
4. Five minutes in a flowing water bath
5. One minute emersion in Kodak Photo Flo wetting agent
6. Drying using blowing cool air

a. Direct Fin-Root Flow Method

Since the flow field in the fin-root junction is assumed to be identical on either side of the fin, then it is only necessary to determine the density on one side of the fin. To accomplish this it is necessary to obtain holograms for 180° of view as shown in Figure 10. The holograms for the views from 0° to 90° can be obtained by using a frosted fin and flat plate as shown in Figure 11. The advantage of having the frosted plate as part of the model is that the fringe/density information obtained by the interferogram is believed to be only for the area between the fin-root intersection to the tunnel wall vice the whole test section, but this was not verified. In order to obtain the fringe information for angles greater than 90° but less than 180° the fin would be exchanged for one containing a stainless steel reflective surface. The scene beam would then enter the test area from the viewing port below the tunnel and be reflected to the hologram plate as shown in Figure 12.

b. Total Model Flow Method

In this method the diffuser plate was located in the scene beam outside the test section as shown in Figure 14 and the flat plate

center section and fin were made of optically clear plexiglas. By translating the diffuser plate between exposures of the hologram, an interferogram of the whole density field in the test section about the model was obtained. From Figure 13 it can be seen that due to symmetry only 90° of view was required to obtain the density field. This makes it much easier experimentally to take the holograms than the previous method described.

3. Schlieren Analysis

A standard Schlieren knife-edge system was used to verify the establishment of the supersonic flow network around the model as shown in Figure 9. Photographs were also taken of the flow with the model at 0° and 90° rotation in order to compare the fin shock conditions with those obtained by Winkelmann [26, 27].

B. PHOTOGRAPHIC TECHNIQUES

By illuminating the holograms with a helium-neon laser beam which has a wave length of 6328 Angstroms, the original scene was reconstructed. Since the original scene beam and the reconstructed beam were of different wave lengths, there is actually a small distortion in the reconstructed scene but of neglectable effect because the hologram plate emulsion in the development process also shrinks.

The typical method for reconstructing the scene is to illuminate the hologram as illustrated in Figure 15. The diffuse glass used in the construction of the hologram appears to act as an infinite light source of non-parallel rays which illuminates the scene. If a small aperture is positioned at the focal plane of the imaging lense, an almost parallel set of rays may then be selected as shown in Figure 16. A third method

illustrated in Figure 17 uses a small diameter conjugate beam to illuminate the hologram. A large depth of field is achieved because the narrow beam acts as an aperture. This effect was of considerable advantage since it enabled both the front and rear grids, the model, and the fringe patterns to be simultaneously projected on the screen. The best photographs were obtained by focusing on the plane of the fringes.

C. DATA REDUCTION

Photographic interferograms were obtained by illuminating the hologram scene with a thin laser beam and using a camera with a viewing screen located in the film plane as shown in Figure 15. The line of sight in the plane desired was achieved by translating the hologram until common points on the front and rear grids were aligned. The camera, with the aperture set wide open at 7.7, was then adjusted to give the best focus on the fringe plane. The best photographic results were achieved by using an exposure time of 1/10 second with Polaroid Type 55 P/N film.

It was felt that the density field could be well defined three-dimensionally along the fin if the density fields were determined in four planes perpendicular to the Z-axis and equally spaced along the fin as shown in Figure 18. In obtaining the fringe data across a constant Z-plane it would be necessary to take six photographs per rotation angle, aligned at appropriate intervals down the y' axis, and then graphically mate the fringe data to form one complete set. The six photos across the field were felt necessary because the optical path length from the model to the hologram plate varied for those points not on the aligned plane.

The fringe shift reduction was accomplished using two different techniques. The first was to project the negative, using a photo enlarger,

onto a sheet of paper and trace out the fringe pattern, model surfaces and grid lines. The light fringes were traced out since it was much easier to judge their center line. From the fringe lines forward of the fin in the region of uniform flow one fringe line which appeared the straightest and compatible with most others was selected as the bench mark. A straight line was then drawn over that fringe and extended past the aligned Z plane (i.e. y' axis). Lines parallel to the bench mark line were then drawn likewise over the remaining fringe lines. The fringe displacements were then read relative to the lines drawn at the points of intersection of the fringes with the y' axis. The radius of the inversion circle was selected so that the fin-root intersection was the origin and the fin tip was the 100 percent point.

In the second technique an enlarged positive photograph was made from the negative. Again one fringe line in the uniform flow region just forward of the fin which appeared to be parallel with the majority of the fringes was selected as the bench mark. The remaining fringes were likewise traced over with lines parallel to the first. The fringe displacements were then measured relative to the lines drawn. For further details see Appendix A.

The locations at which reference lines crossed the y' axis in both techniques above were further adjusted to account for the tunnel wall refraction displacement as shown in Figure 19 and computed by a computer program in Appendix B. Once these corrections were made, the radial variation of the fringe number could then be plotted for the various y' alignment planes and a smooth curve drawn through the data points. The fringe number at 201 equidistant points across the field can then be obtained for input into the computer program, HOLOFER, in MODE 3. For

further details on how to use the computer program, HOLOFER, see Appendix C. Once the data from all the rotation angles of the model have been put into the computer program, the program will then calculate the density field across the inversion circle for that Z-plane. After the density has been calculated for all four Z-planes in Figure 18, a three-dimensional plot of the density field can be made by connecting points of equal density across the fin.

V. EXPERIMENTAL RESULTS AND DISCUSSION

The initial attempts to establish uniform flow over the flat plate shown in Figure 7(a) were unsuccessful due to model vibration and flexure. Movement of the model sting within its holder and flexure of the model plastic center section allowed the model leading edge to establish a little over 1° angle of attack upward when flow was established. Due to various modifications made in attempts to eliminate the vibration, the sting finally fractured.

In an attempt to eliminate these problems, the second model shown in Figures 7(b) and 7(c) was made of a single piece of stainless steel and the sting was mated to its holder to within .001 inches. The model center section was made of poured epoxy and the strakes were both made of stainless steel with plexiglas inserts. The model rotation about the sting was reduced to approximately 0.3° angle of attack upward. Due to the vibration in passing through the transonic range and a weak glue seal between the metal strakes and plexiglas inserts, the inserts were found to break loose. They were subsequently removed and not replaced.

In order to determine the flow field using the direct fin-root approach, the epoxy fin and model center section were frosted on one side using fine

emery paper (see Figure 20). Holograms were taken of the model at rotation angles of 0^{o}, 12^{o}, 45^{o} and 90^{o} using the holographic arrangement in Figure 2 excluding the diffuser plate between lens, L_3, and the test section. The mirror, M_5, was translated in various directions from towards to parallel to the test section between the exposures without flow and with flow established. Fringe patterns were obtained around the model, but only at 0^{o} and 12^{o} rotation could any fringe patterns be observed across the fin. It was found that the fin fringe pattern appeared to remain almost unchanged no matter how or how much the mirror, M_5, was translated while the fringe around the model changed appropriately. For instance, in Figure 21 the mirror was not translated and in Figure 22 the mirror was translated .006 inches horizontally parallel to the tunnel.

Since fringes could not be observed across the flat plate at 45^{o} and 90^{o}, it was felt that the epoxy center section might be too imperfect optically. Consequently double-exposed holograms were taken with no flow through the test section and various translation distances from 0 to .005 inches. The fringe patterns were excellent across the whole model and their spacing decreased according to the increase in the translation of M_5. Next the diffuser plate in the scene beam in Figure 2 was inserted with the model at 0^{o} rotation angle and translated between no flow and flow exposures of the hologram. The fringes about the model were of excellent quality but the double diffusion of the scene beam through the model caused all fringe patterns on the model (fin) to disappear.

It was felt at this point that the fringe pattern obtained across the fin was caused by the movement of the model to an angle of attack and possibly by model vibration, although none was observed visually. The

lack of any fringes across the flat plate center section is not well understood but is believed to be caused by vibration of the model.

Since it was not possible to obtain acceptable interferograms with the diffuser plate as part of the model due to model motion, it was felt that the effect of minor model movements could be eliminated by using an optically clear model and an external translating diffuser plate. Therefore the fin and model center sections were replaced with optically clear plexiglas. With these changes it was found that the flat-plate leading-edge angle of attack had been reduced to approximately 0.1^{o}.

Initially double-exposure holograms were taken using the arrangement in Figure 2 and translating the diffuser horizontally. At 0^{o} model rotation the holographic interferograms were excellent. But as observed in Figure 23 it would be extremely difficult to determine the fringe change across the fin since no free stream reference fringes were available, due to the flat plate leading edge Prandtl-Meyer expansion and fin shock intersecting the tunnel top just above the fin. With a larger tunnel or smaller model this would be an excellent technique.

The diffuser plate was then translated vertically between exposures and excellent horizontal fringe patterns were obtained as shown in Figure 24. The model was then rotated to $22\frac{1}{2}^{o}$ and the same holographic technique was used. Excellent fringe patterns were obtained above and below the flat plate center section. Fringe patterns across the flat plate center section and fin in this area were very light and usable interferograms could not be photographed with the polaroid camera. In an attempt to improve on the fringe quality, polarizer plates were inserted in the reference beam between the mirror, M_4, and the hologram plate and in the scene beam between the lens, L_3, and the diffuser plate in order to ensure

polarization of both beams. No significant improvement could be noticed and they were subsequently removed. A one-quarter wave polarizer plate was then placed between the lens, L_1 and the beam splitter in order to utilize circularly polarized light for the reference and scene beams. Okayama and Emori [14] found that their image resolution improved considerably; however, with this particular arrangement little to no improvement in the fringe resolution was observed and the approach was abandoned.

The transverse mode selector was then varied from 2.0 mm. to 1.5 mm. and later to 1.0 mm. in an effort to improve the coherency length of the laser light and consequently the image resolution. Due to the decrease in output light intensity, up to six exposures were taken during a run with flow established. Image and fringe definition were not found to increase possibly due to model vibration which was not visible to the eye.

The model was rotated to 45^o and $67\frac{1}{2}^o$ and double exposure holograms were taken with a 2.5 mm. transverse mode selector. There were no observable fringe patterns in any portion of the test section. Consequently it was believed that supersonic flow was not established due to tunnel blockage caused by the shock wave from the model and by slight model vibrations in passing through the transonic range. In the transition to supersonic flow, the model leading edge would sometimes flex as much as 0.2^o depending upon the transition time.

The test section walls were changed from the total plexiglas side walls shown in Figure 1(a) to the aluminum walls with the optical quality glass port holes (Figure 1(b)). The better quality glass would hopefully improve the viewing and the port holes made the model much more accessible. The metal strakes were also removed from the model since they appeared to have a minimal effect on the flow, were an interference optically,

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flow was established. The plate leading edge shock and fin shock appeared quite fuzzy and light. Due to oil from the tunnel supply reservoir mixing in the flow, a light oil smear pattern can be observed across the fin in Figure 26. During one run, which could not be duplicated, the model pitched up as flow was established but did not vibrate. The plate shock and Prandtl-Meyer waves, fin shock system, and tunnel Mach lines became very distinct and well defined as seen in Figure 27. The schematic of the Schlieren photographs in Figure 28 points out the cause for the various flow lines observed. The non-uniformity of the free stream caused by tunnel leakage can be easily seen. Consequently the experimental work was discontinued due to tunnel conditions and time considerations.

It was felt at this point that if the holographic interferogram taken of the clear plexiglas fin at 0° rotation angle could be reduced to useful data for the computer program then the holographic method would be to a certain extent verified even though the actual density field could not yet be determined.

In obtaining interferograms from the hologram, the reconstruction technique shown in Figure 15 was used. The plane of constant Z across the model to be reduced was chosen to be the forward most vertical grid line crossing the fin. It should be pointed out that in order to simplify the hologram alignment process, all four reduction planes across the model should have been scribed on the exterior grids. The three photographic points across the Z plane on the y' axis were, for convenience, chosen to be where horizontal exterior grid lines crossed the y' axis on the fin. Five interferogram photographs were taken at points A, B, and C as shown in Figure 29. Photographs 2 and 5 were taken using a Kodak Wratten Gelatin Filter N.D. 2.0 placed in the reconstruction beam in order to reduce the

beam intensity and increase the fringe definition. These two photographs were also used to provide a check on the consistency of the reduction process.

All five negatives were blown up on the photo enlarger in the dark room and the plate, fin, grid lines and fringes were traced out on a sheet of white paper as shown in Figures 30-34. It was very difficult to trace the fringes in the region of the fin tip and fin root due to the photographic resolution and the fin tip shadow. Also fringes were not visible in the region of the fin leading edge shock. Consequently, connecting the fringe in front of the fin to the correct fringe on the fin was a best guess effort. Typical of the problem was that fringe lines in two of the drawings were initially improperly connected across the fin leading edge shock. After being checked against the photograph negatives,the fringes were reconnected and the data taken correlated well with the data from other drawings. The fringes in the fin root area were extremely light in some photographs which made it quite difficult to determine their centerline crossing the y' axis.. Another point of difficulty was determing the location of the top and bottom of the fin. An error in drawing here will have an effect later when the fringe locations are normalized with respect to the fin height.

Enlarged positives were then made from the negatives as shown in Figures 35-39 to see if the data accuracy could be improved by eliminating the difficulties of tracing the fringes in the dark room. This method also made it possible usually to reassess the assumed path of the fringe lines at a later time if the data did no appear to correlate properly. The same problems of locating the fringe lines in the region of the fin tip and of connecting the fringe lines across the fin shock are readily apparent in the figures.

To obtain the fringe change across the fin one of the straightest fringes in the free stream region which paralleled the majority of other free stream fringes was selected. A straight line was drawn through its centerline and extended to cross the y' axis. The other free stream reference lines were then drawn parallel to the first and adjusted so as to best follow the centerline of the selected fringe. This method actually averages the free stream conditions and is only valid if the free stream is essentially uniform. Sinceit was not possible to obtain in the photographs the free stream fringe pattern forward of the leading edge Prandtl-Meyer expansion for the lower fin region, the fringe reference lines in photo enlargements were drawn over the fringes just prior to the fin shock. In order to adjust them to free stream conditions their location was moved downward a distance equal to 1.1 times the average fringe interval for that photograph. The figure 1.1 was observed in all the enlarged photographs to be the approximate fringe change across the Prandtl-Meyer expansion. In the drawings (Figures 30-34), fringe reference lines for the lower fringes (generally $y' < .8$) were initially aligned along the straightest portion of the fringe prior to intercepting the fin shock. By comparing the reference line location on the drawing with the fringe pattern in the photographic enlargements the reference line location and fringe change were adjusted by an appropriate portion or all of the 1.1 fringe change caused by the Prandtl-Meyer expansion. All of the reference lines were then corrected for the tunnel wall and grid plastic parrallax shown in Figure 19 and computed in Appendix B. The reference fringe locations were then normalized with respect to the wing height and the fringe numbers calculated by dividing the fringe change by the average fringe interval. For further details and calculations see Appendix A.

The data obtained for alignment points A and C by the two different reduction processes are plotted in Figures 40-43. The data obtained from the photo enlargements aligned at point C and shown in Figure 43 gave the best data agreement between two photographs. The worst data agreement was obtained from the reduction of the drawings aligned at the same point. The inconsistency in the data was probably caused by connecting the wrong fringe lines across the fin leading edge shock. The data fluctuations and discrepencies between the curves in the figures could have been caused by a number of things. It could have been caused, for instance, by not drawing the fringe reference line parallel to or exactly on the free stream fringe center line or slightly missing the fringe center as it crosses the y' axis or by misconnecting fringe lines across the fin shock as was illustrated in Figure 42 Fringe location errors could be caused by misdrawing the fin tip and root lines as was mentioned earlier. Another contributer would be measurement errors.

To analyze these sources for error, first consider that the typical fin size in the drawings and photo enlargements averaged about 2.5 inches high and 2.75 inches wide and that the fringe spacing averaged about 0.10 inches. All measurements were taken using a ruler graduated in 0.01 inches and readings were made to the nearest .005 inches. Since the average difference between the data points and curves ran around ¼ fringe, some figures were calculated to determine what measurement errors could produce this fringe error. It was found that an error of .025 inches in alignment of the fringe reference line with the free stream fringe center line and/or fringe center line crossing the y' axis could produce ¼ fringe error. This fringe error will also occur if the fringe reference line differs from the free stream center line by more than 1.4^{o} when drawn 1 inch from the y' axis or by more than 0.36^{o} when drawn 4 inches from the

y' axis. A difference of .01 inches in the average fringe interval could also produce a ½-fringe error; however, this is not too likely since it is an average of fifteen to twenty-five intervals. By comparing the actual height-to-width ratio with those found in all the drawings and photo enlargements it was found that average error was around 2% or a distance of .02 on the y'-axis.

In order to compare the interferogram negative quality and the two different reduction techniques, a plot of the data for each negative was made as shown in Figures 44-48. Photographs 1 and 3 in Figures 44 and 46 gave the smoothest curves indicating the highest interferogram resolution. Photograph 5 (Figure 48) gave the worst dispersion indicating poor interferogram resolution; yet looking at the enlargement in Figure 39, the fringe line contrast is very good. In comparing Figures 40-48 it appears that the reduction technique using the photographic enlargements gave the most consistent data. This technique also provides a much easier and faster recheck on the proper tracing of fringe lines because it is extremely difficult and tedious to duplicate the fringe pattern to the same scale over the drawings using the photo-enlarger in the dark room.

All the data obtained by either method for one alignment point were then plotted in Figures 49 and 50 in order to observe the dispersion. A fringe number dispersion of about 0.6 fringes was observed in the data taken from the negatives aligned at point A and a dispersion of about 0.8 fringes for the data about point C. The dispersion is attributable to the inaccuracies in the drawings, to the photographic quality of the interferograms, and to the inaccuracies in correcting the lower fringe reference lines to free stream conditions. The last point is based upon the increased dispersion between the fin tip and fin root data.

Figures 51 and 52 show an integrated curve of the fringe change across the wing as determined by each reduction method. In constructing the curve, the data from the three aligned points was plotted so as to just overlap each other. These two curves were then compared in Figure 53. The maximum variation in the fringe number is about $\frac{1}{2}$ a fringe but the variations in the location of the fringe maximums and minimums average about 0.1 inches on the fin. The location difference is probably due to improper drawing of the fringe reference lines compounded with not being able to measure the wing height accurately. Due to the inaccuracies introduced in tracing the negative and then reducing the data it is felt that the photo enlargement method is the more accurate reduction method.

With fringe data from only one field of view, the density field, obviously, could not be obtained. It was felt useful to consider the flow field axisymmetric in order to exercise the computer program and to provide a check on the program's ability to handle these particular curve shapes. Fringe data at 101 equidistant points across the fin from $0 \leq Y' \leq 1.0$ was obtained from Figure 53 for both curves and fed in HOLOFER in Mode 3 for the axisymmetric case. For further details on HOLOFER see Appendix C. The scale factor, α, in Equation 9 was then varied from 0.2 to 2.5 and a value to 1.0 was determined to yield the most accurate density solutions. This value was verified by feeding the function data, $(\rho/\rho_\infty - 1)$, calculated by Mode 3 back into the program in Mode 1 and comparing the fringe data calculated with the original fringe data obtained from Figure 53.

The density distribution for both the drawing and photographic reduction cases is plotted in Figure 54. The density as Y' approaches zero actually goes as the drawn lines even though the points indicate a dip.

Matulka [12, 13] pointed out that the computer program accuracy does not converge at the origin. The large variations of the density curves at values of $Y' > 0.8$ are caused by the program trying to adapt to a step or shock wave type function at $Y' = 1.0$. If the remainder of the fringe data in Figure 53 for values of $Y' > 1.0$ had been included as input data the density curves would have smoothed out. This shock wave step function effect was demonstrated and analyzed by Matulka [12, 13].

The low values of density for the photographic data curve around $Y' = 0.38$ were unexpected but not surprising. First, the photographic fringe data curve is more extreme than the drawing fringe data curve and second, the density curves are not true values anyway since the field was considered axisymmetric and this is not the case in reality.

In general the density curves are felt to be reasonable under the assumed conditions. Consequently it is believed that the computer program could very easily and accurately handle a complete analysis of the flow field around the fin-flat plate.

In completing the analysis there are some data reduction problems which would have been encountered in reducing the interferograms at other model rotation angles which merit discussion. With no model rotation, adjusting the fringe reference lines close to the fin root to account for the leading edge Prandtl-Meyer expansion was relatively easy. However, when the model is rotated, the fringe shift across the Prandtl-Meyer expansion can no longer be considered a constant and it will be very difficult to adjust the fringe lines at lower values of Y' to free stream conditions. The best solution would be to increase the scene beam diameter and/or reduce the model size in order to photograph the free stream fringe lines forward of the plate leading edge. The free

stream lines could be connected to the appropriate fringe lines forward of the fin and this would eliminate the numerical correction and increase the fringe data accuracy.

Also at the rotated angles, fringe information will not be available for portions of the reduction plane due to shadows cast by the model sides as shown in Figure 55. In the lower portion of the hologram the fringe curve can be connected with a smooth line because the density field in that portion should be essentially constant. Care must be taken in completing the curve, though, since this information will be used in the integration of other rotation angles. The fringe curve in the upper portion must also be completed carefully but should be easier since the shadow will be smaller. For this particular model it was calculated that for angles greater than 46.6° the upper shadow would not penetrate the fin.

There are two more problems to be coped with which do not have apparent solutions at this time. The first has to do with the superimposing of fringe information from different locations onto one scene beam line as illustrated in Figure 56. In case I the superimposing of the fringe change in Region A onto that in Region C and locating the fringe reference line at point C' is tolerable because the density field in Region A should be fairly constant and uniform. However in case II where the fringe change in all three regions are superimposed and located at point C", the answer is not readily apparent. If the plate and fin were of equal thicknesses then points A" and C" would be the same and the error would be somewhat reduced. If, in addition, the thicknesses were made as thin as structurally possible, the error would be reduced to a minimum. Also it might be possible to integrate the model geometry into the computer program but this has not been attempted.

With the model at rotation angles between 0° and 90° scene beam defraction at the fin root and tip areas would also present problems as seen in Figure 57. A minimization of the problem could again be achieved by minimizing the fin and plate thicknesses.

VI. CONCLUSIONS AND RECOMMENDATIONS

The investigation, although not totally successful, has demonstrated the feasibility of using holographic interferometry to determine the flow field around a transparent model by looking through the model. The problems of model vibration and movement, of superimposing different fringe information on one beam, and of scene beam divergence through the fin root and tip regions must still be solved. The model vibrations and rotation to an angle of attack are attributable to the tunnel pressure fluctuations caused by tunnel leaks and to possible movement of the sting holder. It is felt that all three problems could be decreased to neglectable effects by reducing the overall model size and by incorporating the model geometry into the computer program.

The basic holographic arrangement was found to work quite well for this type of experiment. The holograms were generally high quality except when unfavorable tunnel flow conditions existed. The use of circularly polarized light recommended by Okayama and Emori [14] did not increase the hologram resolution appreciably but the method merits further considerations because of their excellent results.

The data reduction process was found to be the rate-controlling step in the investigation due to the time and labor involved. Reducing the data from enlarged photographs of the interferogram saved some time and appeared to increase the data accuracy. The data scatter of ± 1/8 fringe

was considered acceptable considering the fringe resolution in the holograms. It was felt that this could be reduced by using either a larger tunnel or a smaller model. With either of the changes it would be possible either to use the free stream fringe pattern forward of the model as the reference conditions across the whole model or to use a vertical fringe pattern, since the leading edge Prandtl-Meyer expansion and fin shock would not block out the free stream fringes above the fin. It appears that the use of vertical fringes would also considerably reduce the data reduction time.

With the use of Schlieren the flow network described by both Thomas [23, 24] and Winkelmann [26, 27] was verified to exist. From the top view (90° model rotation) the fin shock and its fluctuations were observed and photographed through the flat plate plastic center section.

The computer program, HOLOFER, was found to be quite capable of handling the type of flow field fringe data which would be generated in a complete analysis of this type. As pointed out before it is believed that the program should be modified to incorporate the model geometry.

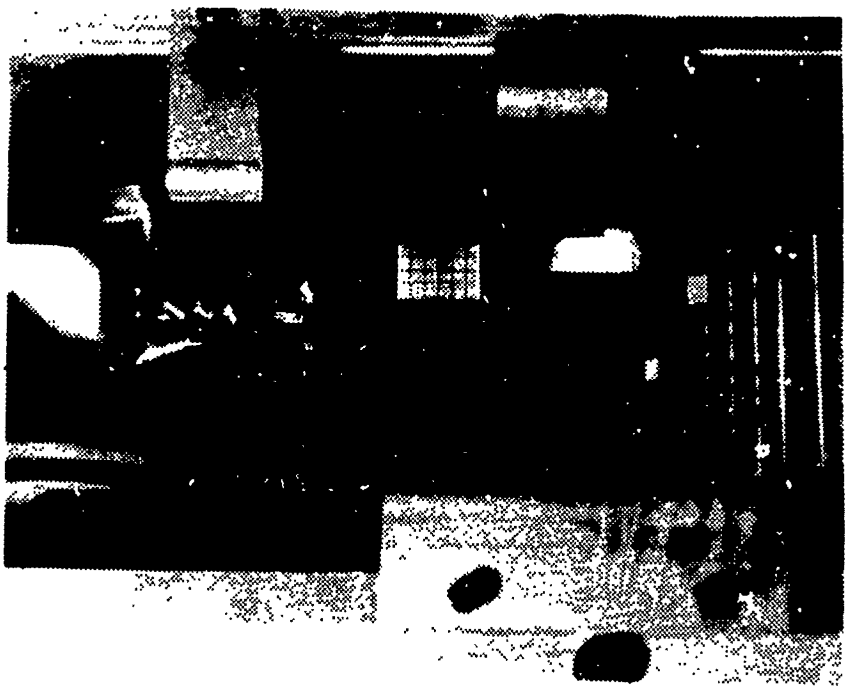

Figure 1(a). Wind Tunnel Test Section with Clear Plastic Side Walls

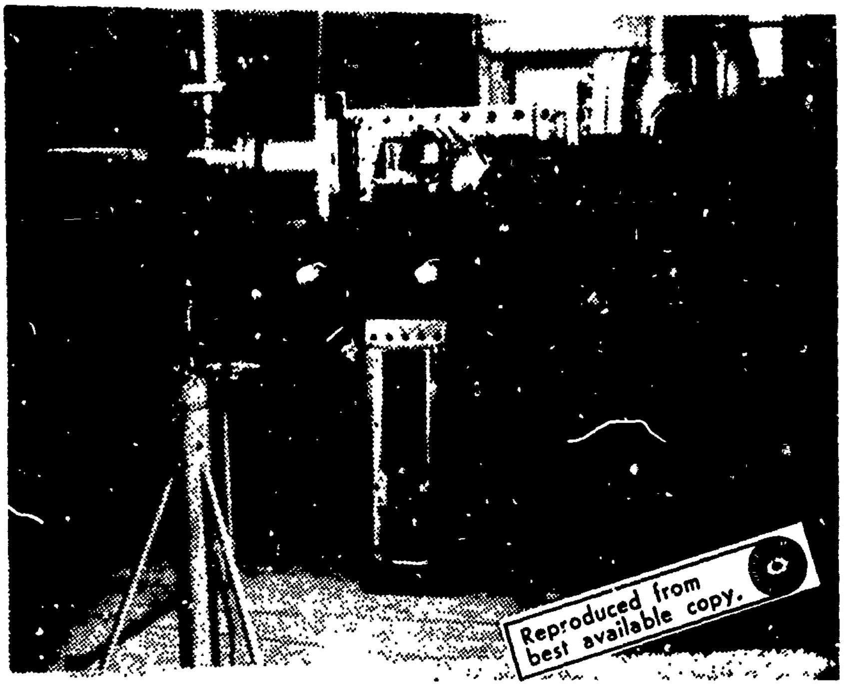

Figure 1(b). Wind Tunnel Test Section with Aluminum Side Walls

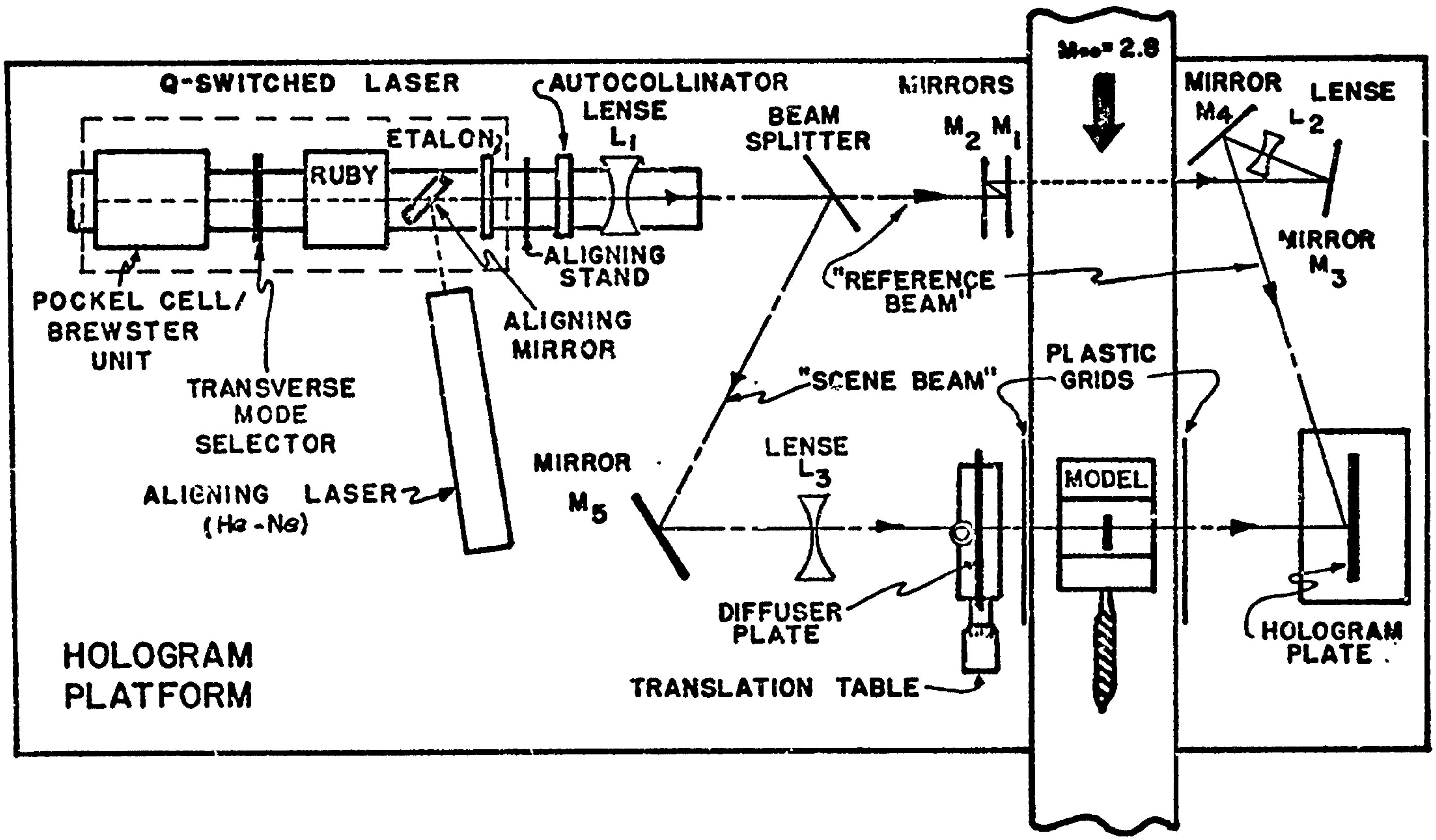

Figure 2. Schematic Representation of the Holographic Arrangement

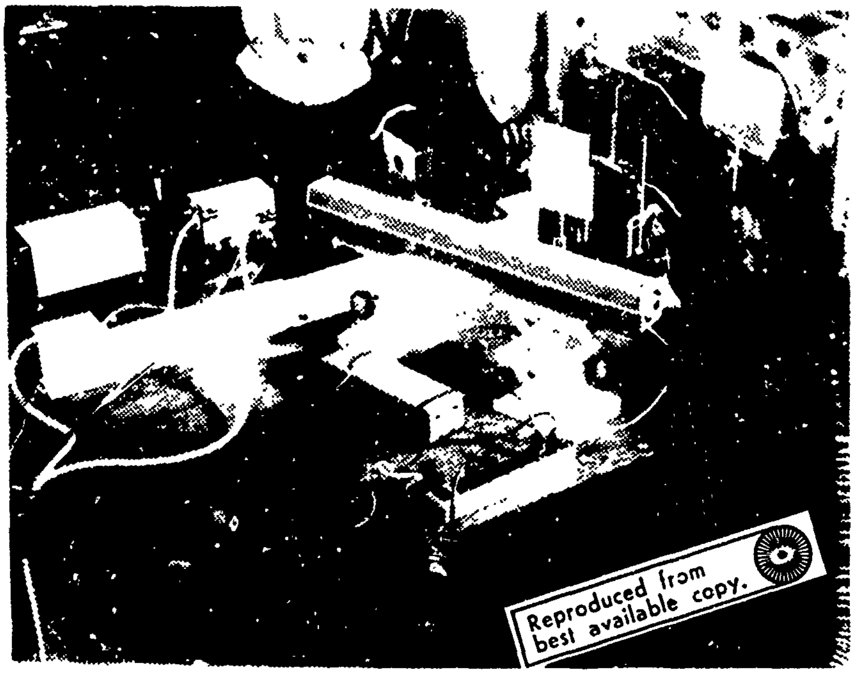

Figure 3. Holographic Arrangement Including the Laser Cooling and Aligning Equipment

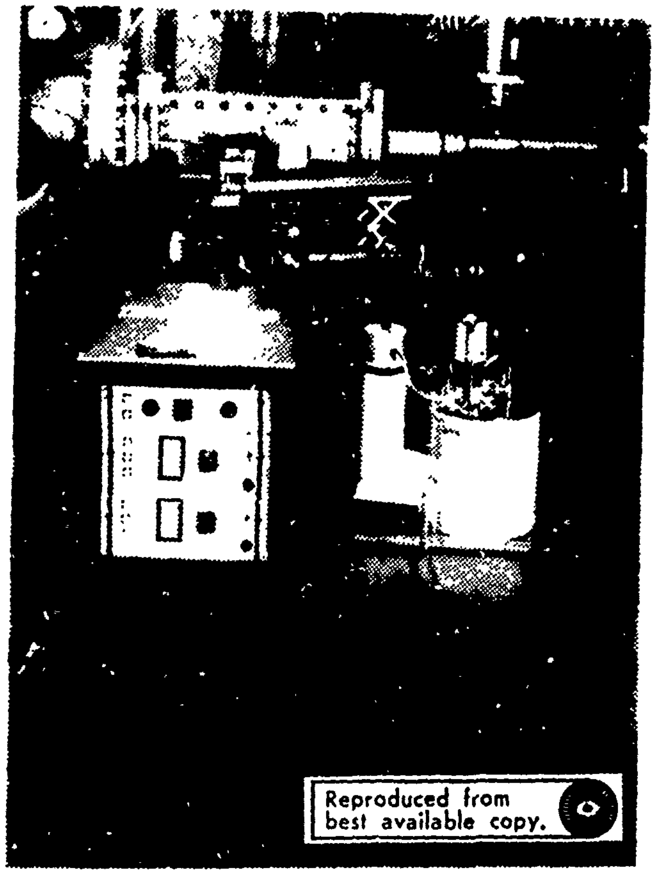

Figure 4. Ruby Laser Power Supply and Cooling Unit

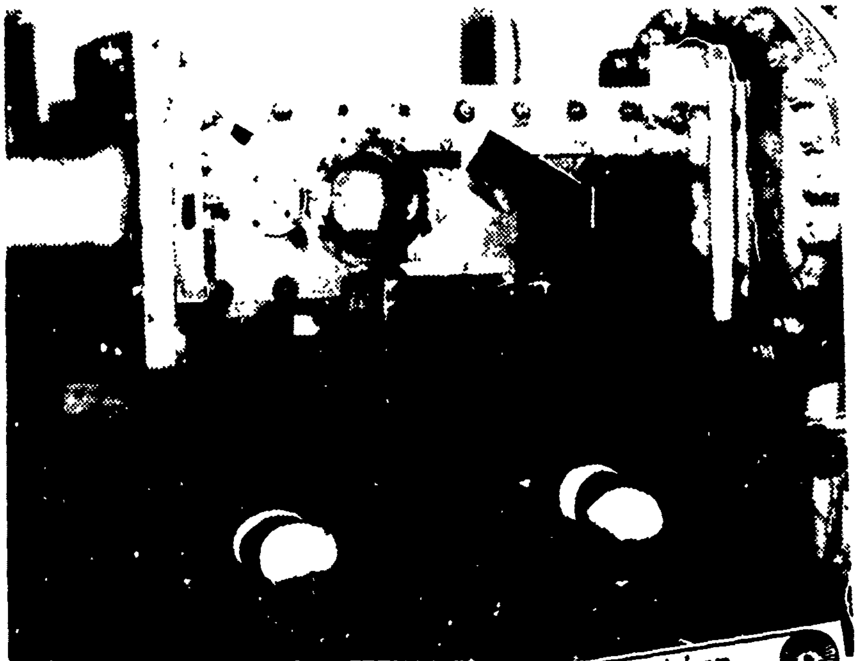

Figure 5. Hologram Plate Holder and Mirrors on the Reverse Side of the Wind Tunnel

Figure 6. Hologram Platform Box Cover for Daylight Photography

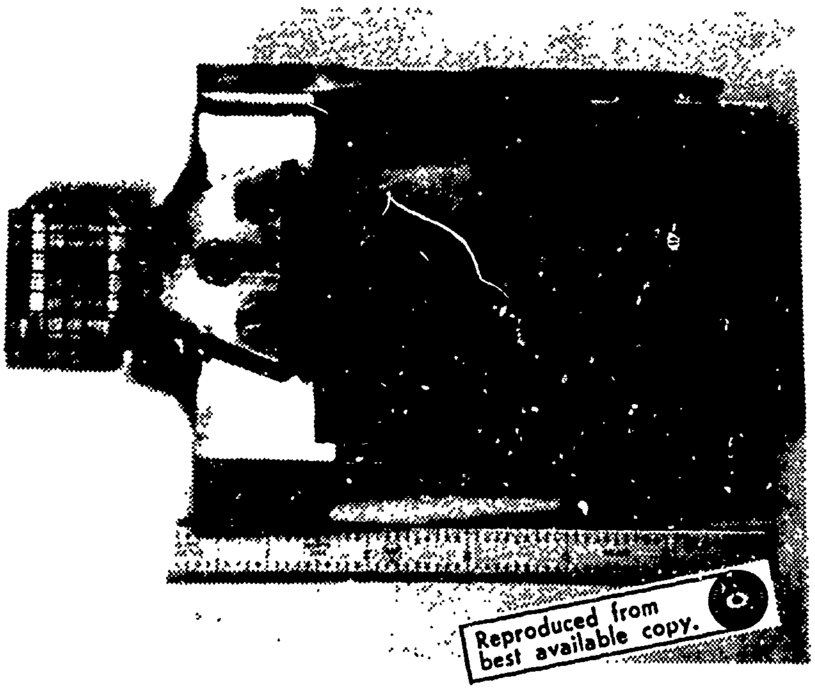

Figure 7(a). Initial Fin-Flat Plate Model Used in the Experiment

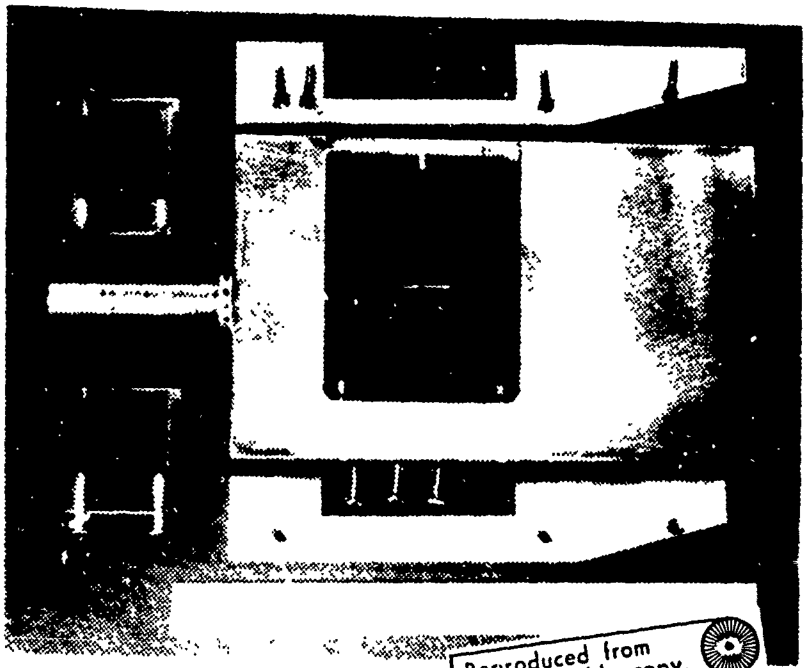

Figure 7(b). Second Fin-Flat Plate Model Used in the Experiment

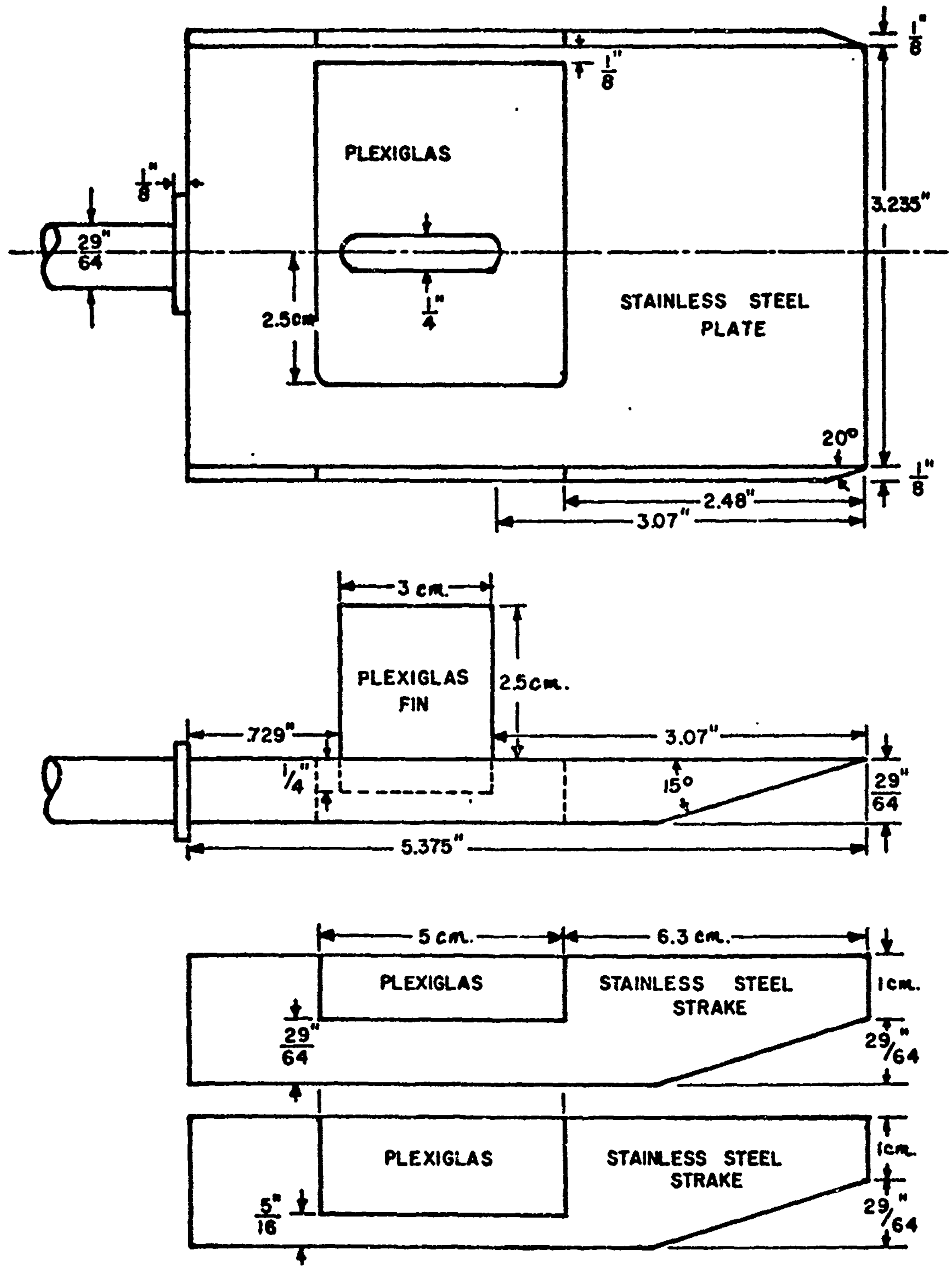

Figure 7(c). Details of the Second Fin-Flat Plate Model

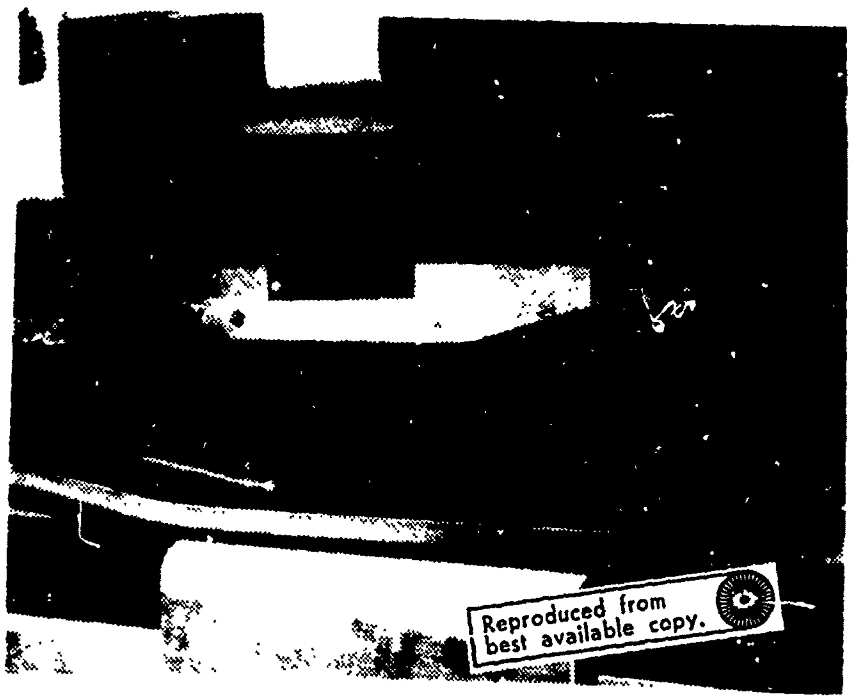

Figure 7(d). Model Mounting in the Wind Tunnel Test Section

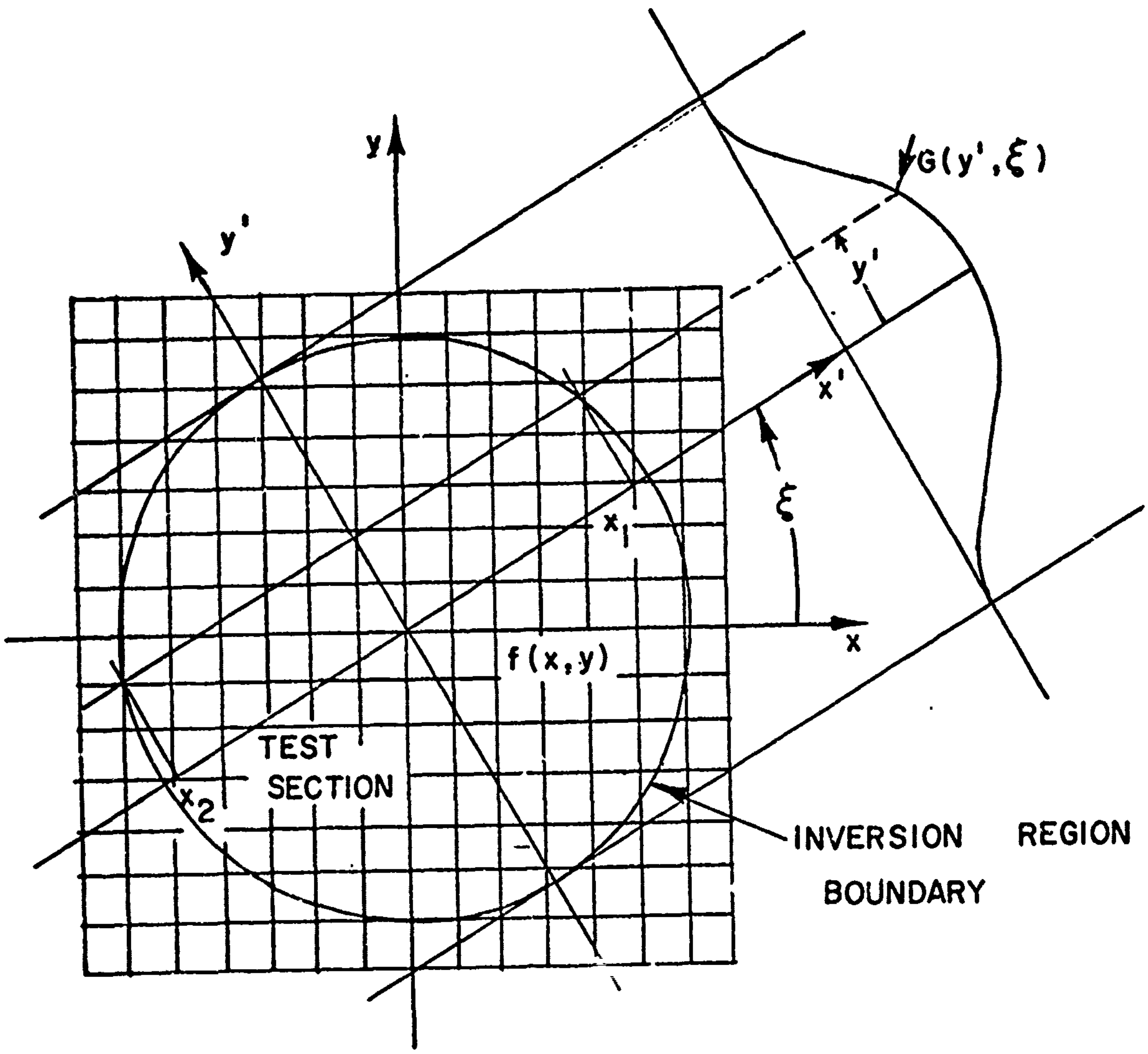

FIGURE 8. CO-ORDINATE SYSTEM USED FOR THE INVERSION OF FRINGE NUMBER TO DENSITY

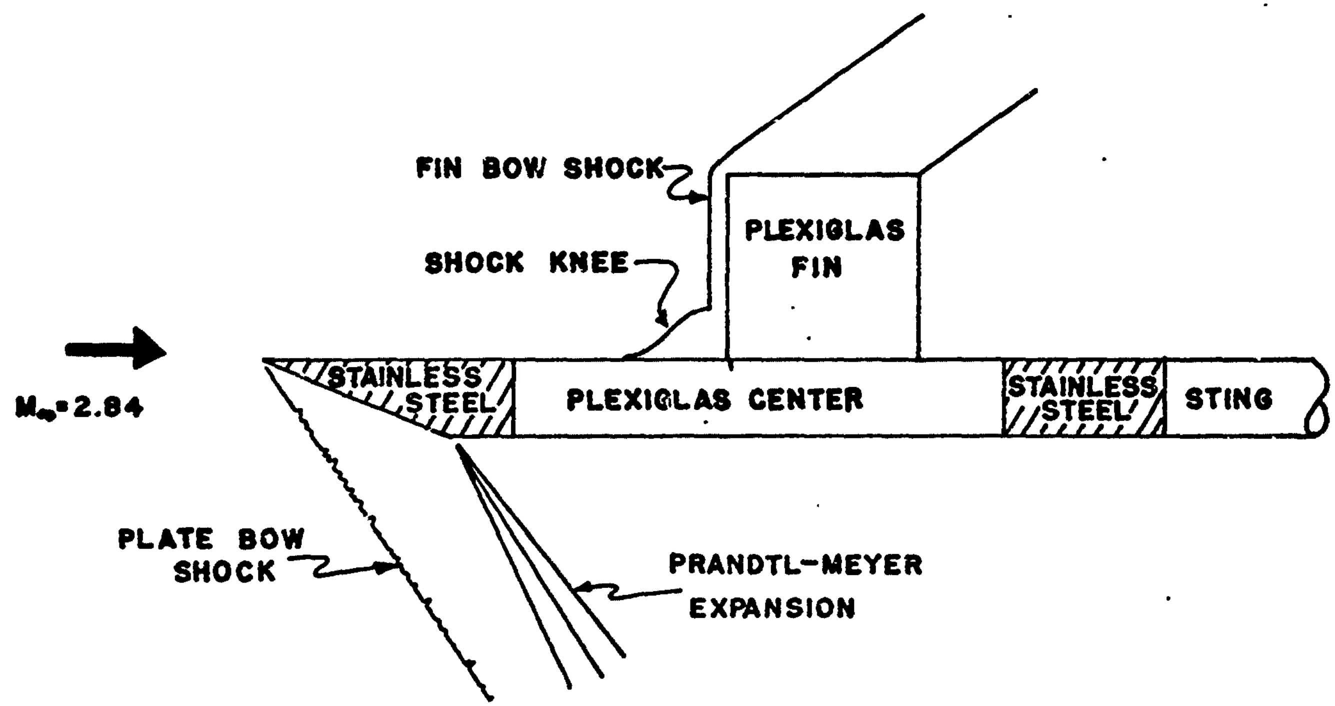

Figure 9. Schematic of the Desired Model Flow Network

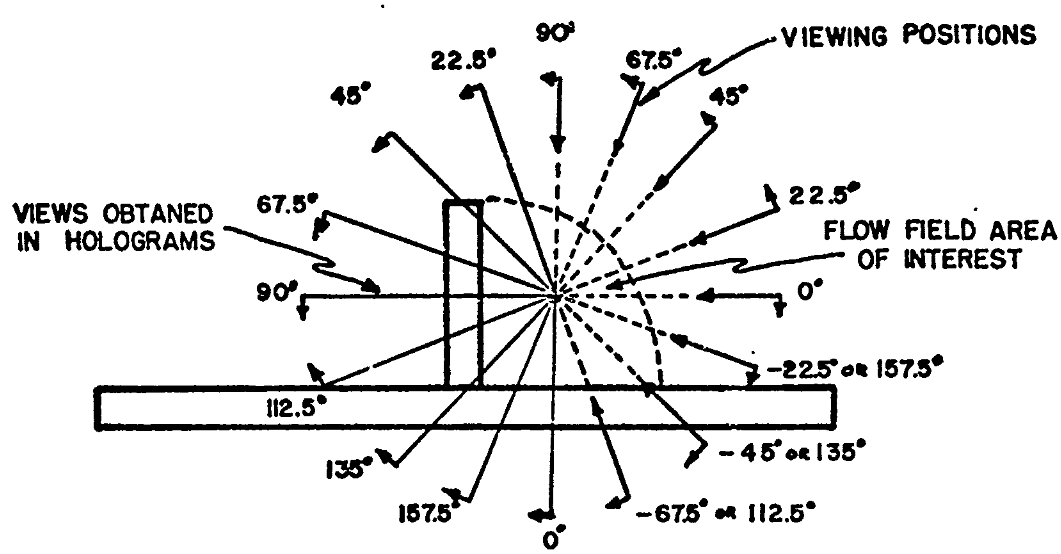

Figure 10. Desired Holographic Views in the Direct Fin-Root Method

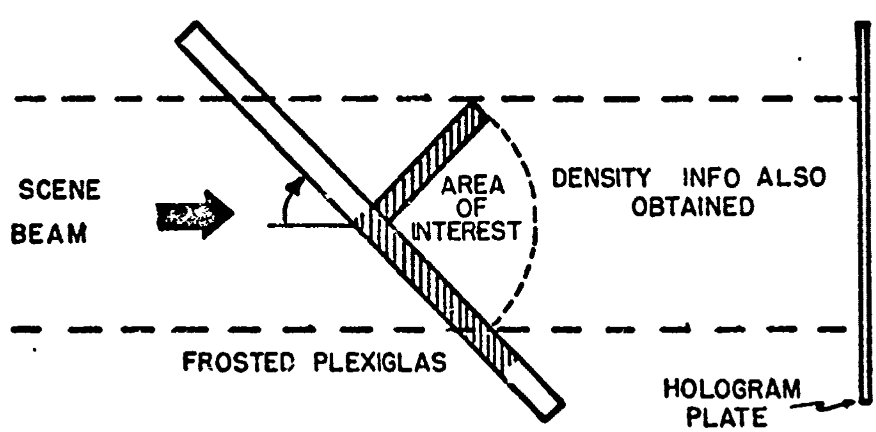

Figure 11. Schematic of the Model Used to Obtain Holographic Views Between 0° and 90° in the Direct Fin-Root Method

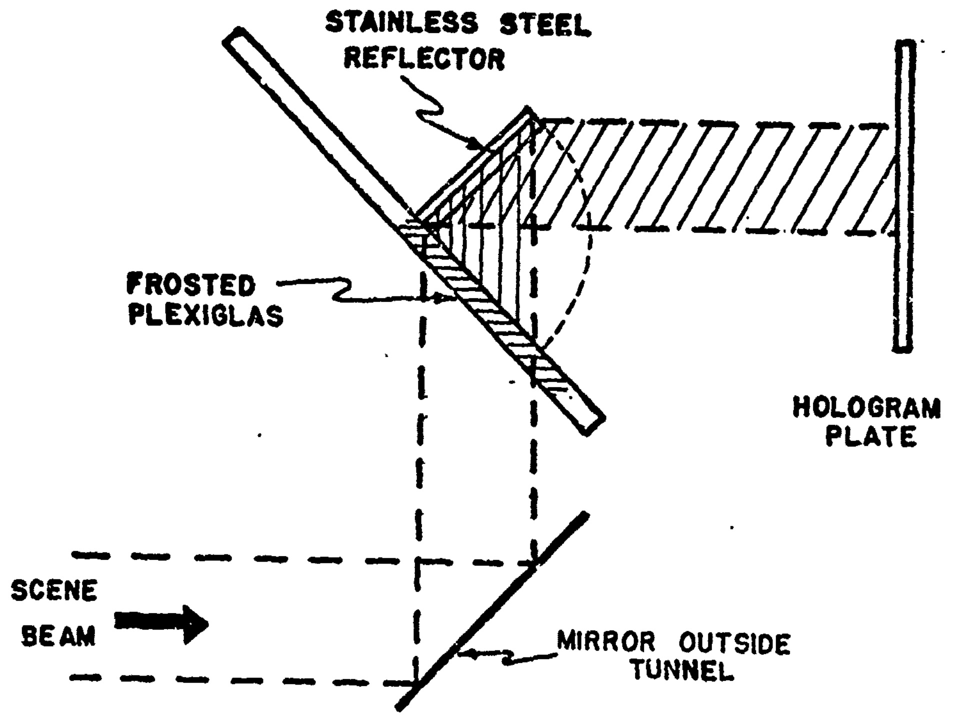

Figure 12. Schematic of the Model Used to Obtain Holographic Views Between 90° and 180° in the Direct Fin-Root Method

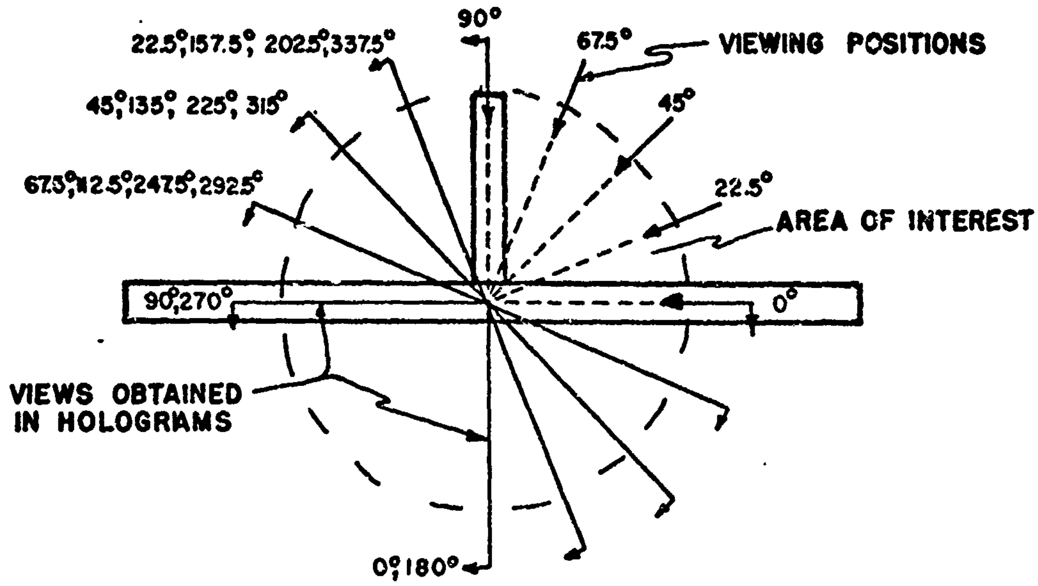

Figure 13. Holographic Viewing Angles Required in the Total Model Flow Method

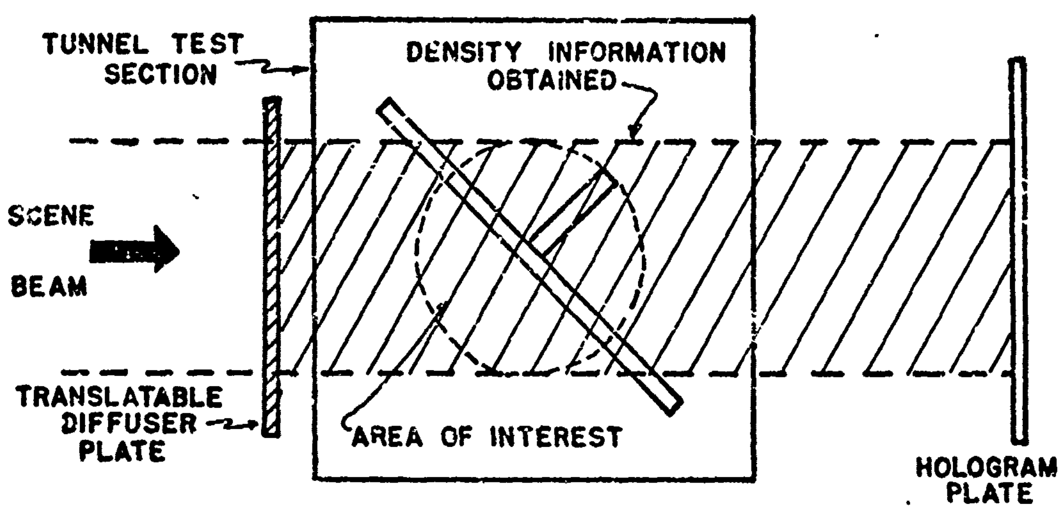

Figure 14. Schematic of the Technique Used to Obtain Holograms in the Total Model Flow Method

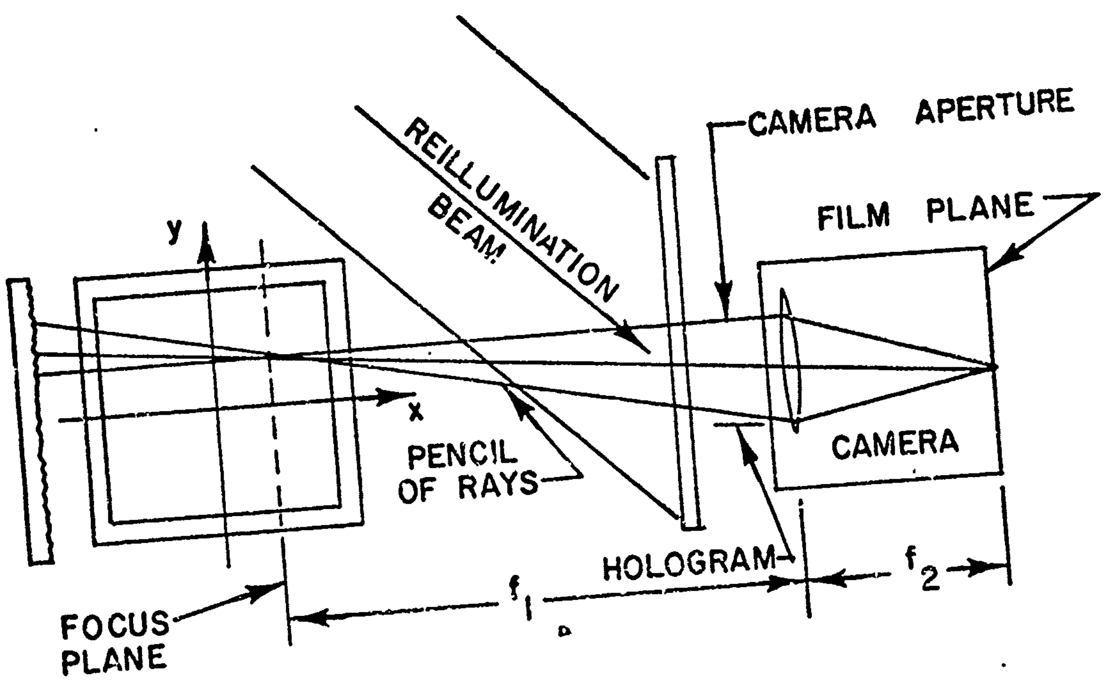

FIGURE 15. EFFECT OF APERTURE SIZE FOCUS PLANE POSITION ON THE PENCIL SIZE OF RAYS ABOUT A LINE OF SIGHT RECORDED BY CAMERA

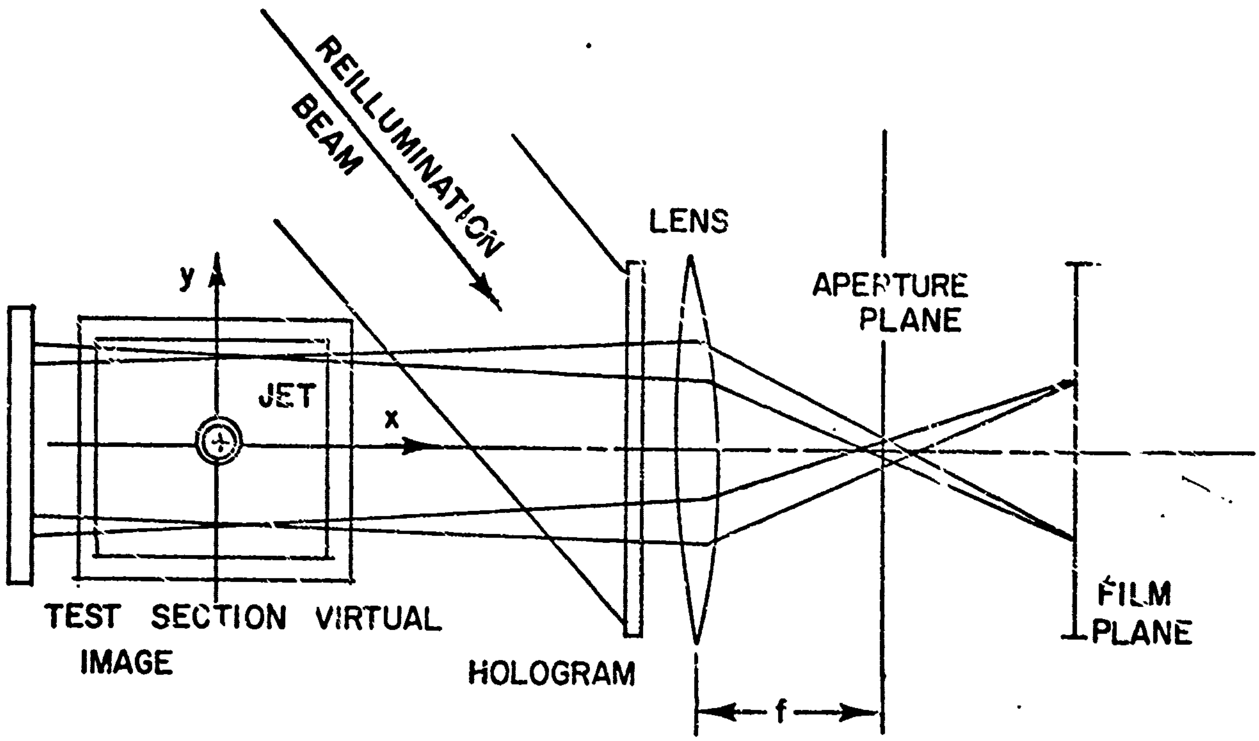

FIGURE 16. SPATIAL FILTERING TECHNIQUE FOR SELECTING PHOTOGRAPH OF CONSTANT ANGLE LINES OF LIGHT

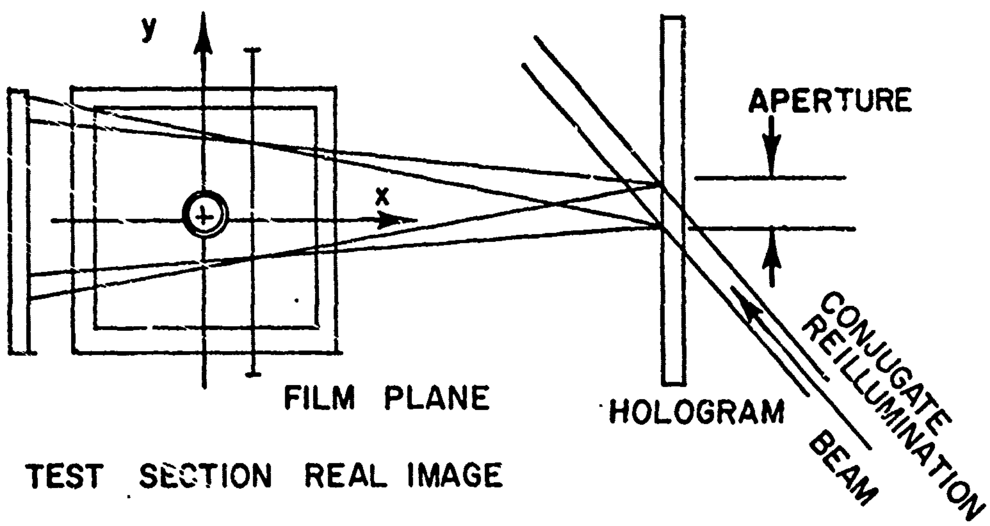

FIGURE 17. LENSLESS PHOTOGRAPHIC TECHNIQUE USING A CONJUGATE REFERENCE BEAM OF SMALL DIAMETER

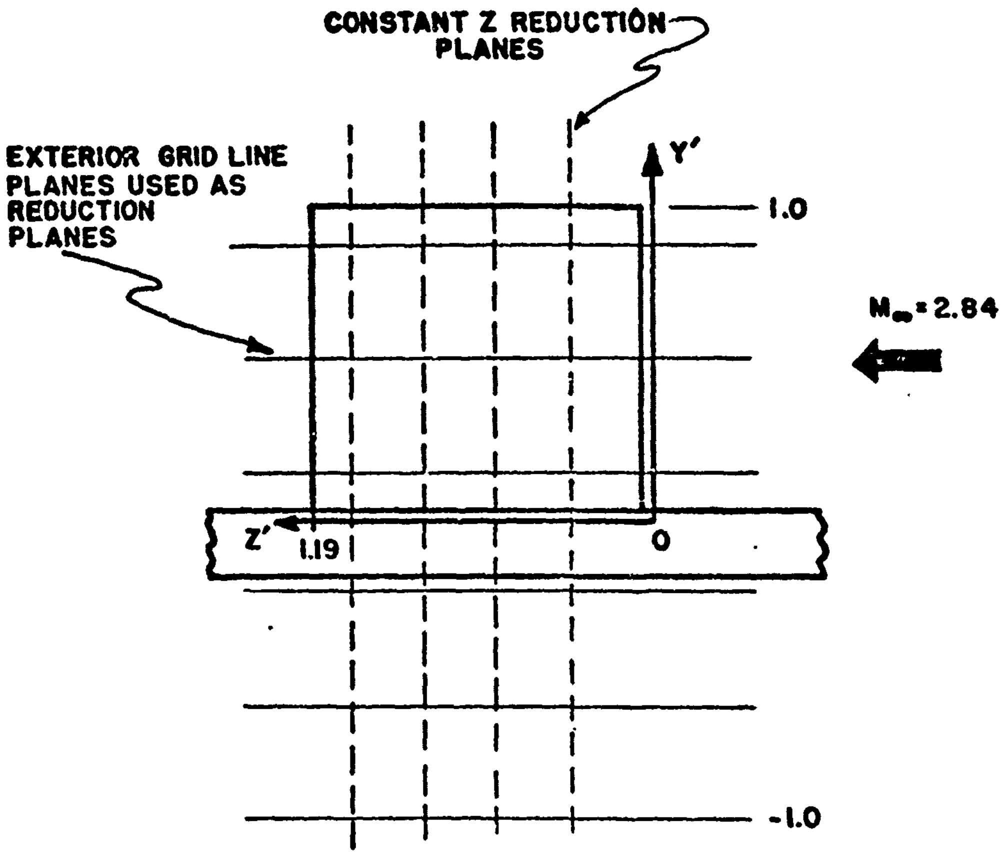

Figure 18. Data Reduction Planes Desired to Describe the Density Field Down the Fin

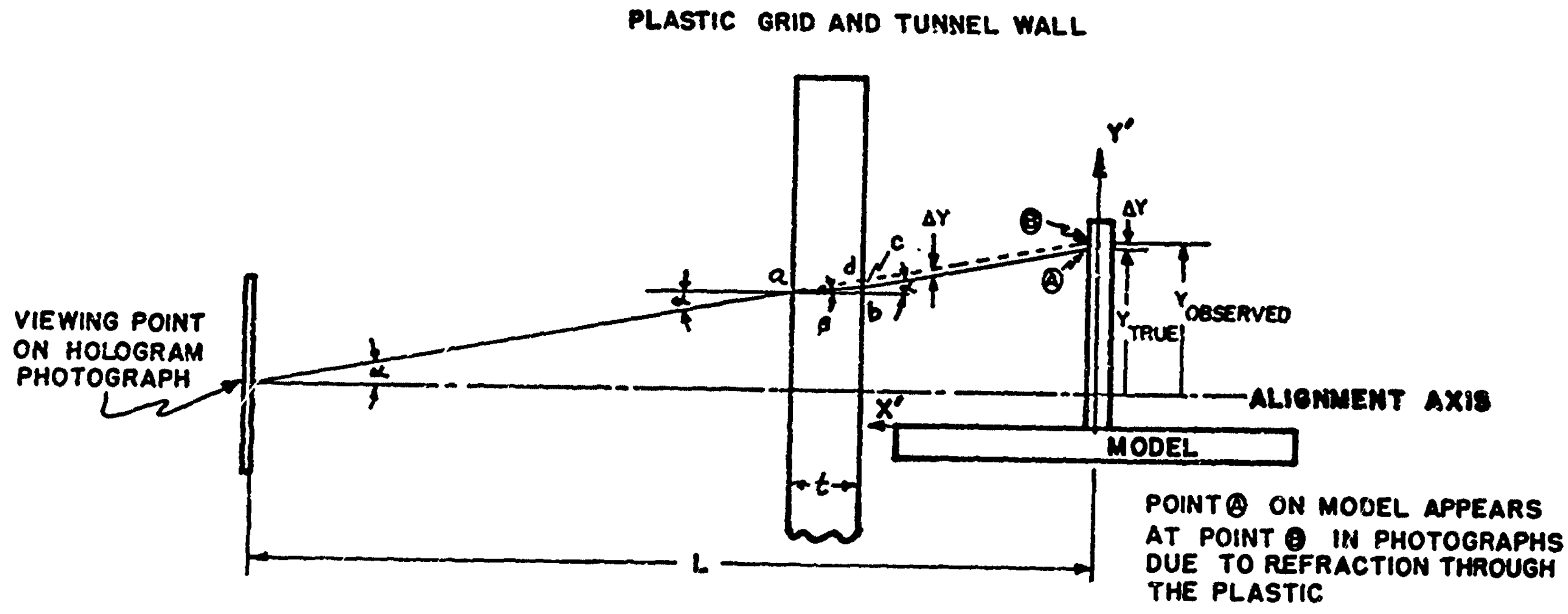

Figure 19. Schematic of the Refraction Displacement in the Photographs of Points Not Located on the Aligned Axis Caused by the Plastic Grid and Tunnel Wall

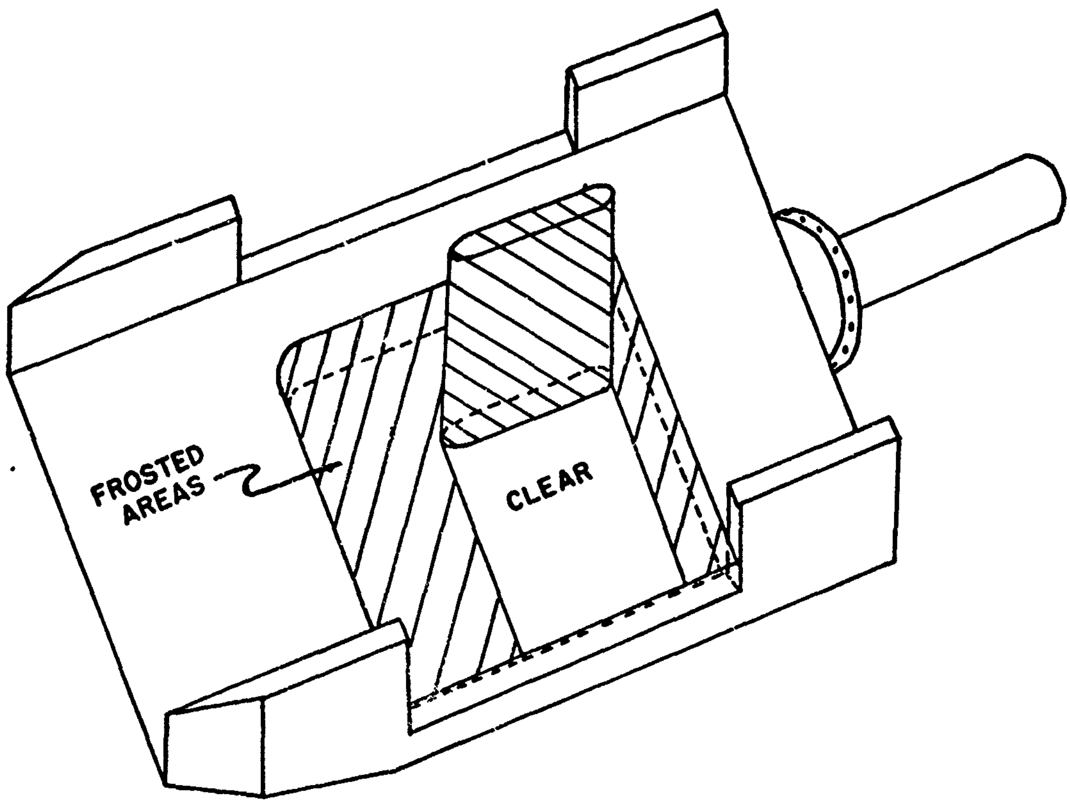

Figure 20. Schematic of the Diffused Plastic Portion of the Model Required in the Direct Fin Flow Method

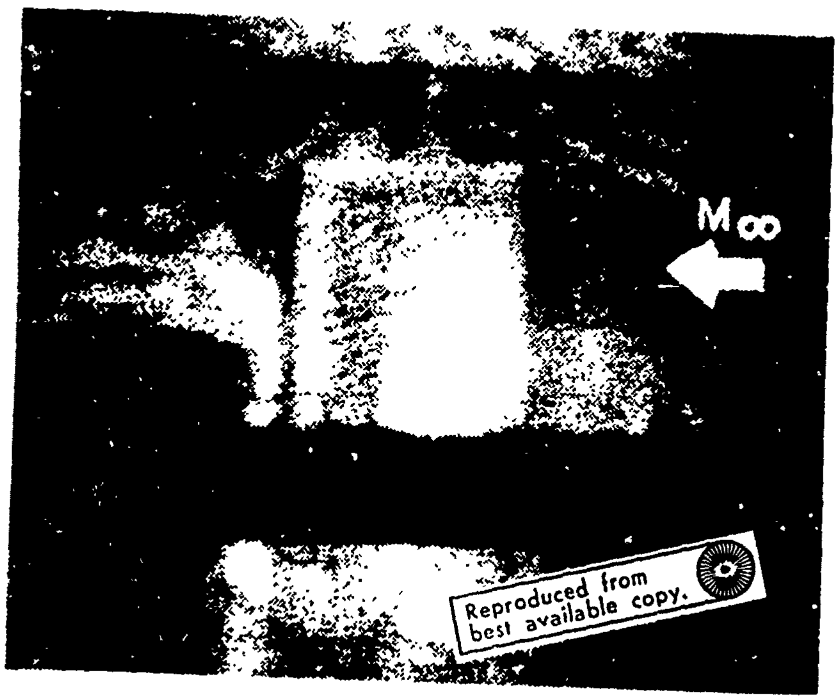

Figure 21. Interferogram Obtained in the Direct Fin Flow Method with the Model at 0° Rotation, Mach 2.84 and no Translation of Mirror, M_5

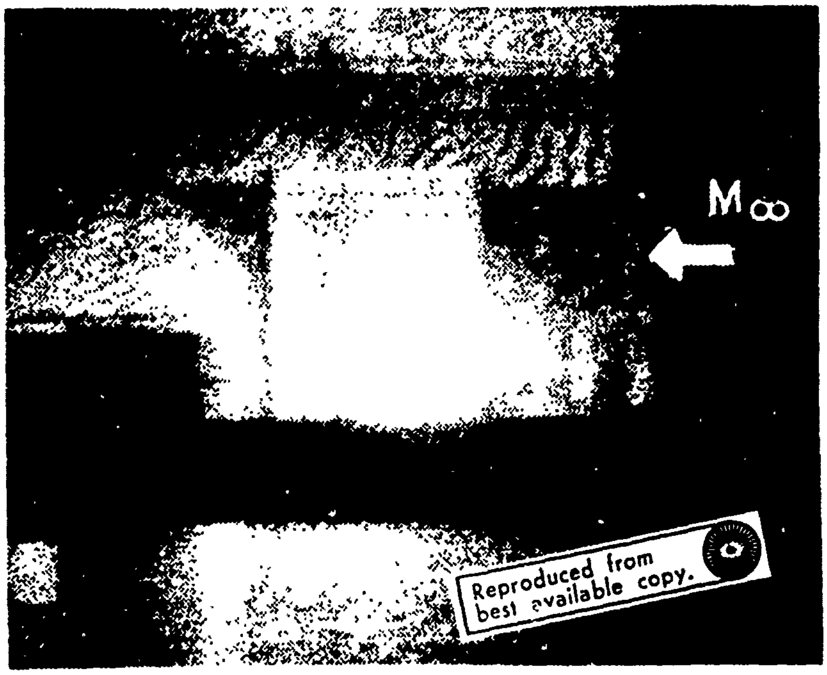

Figure 22. Interferogram Obtained in the Direct Fin Flow Method with the Model at 0° Rotation, Mach 2.84 and a .006 inches Translation of Mirror, M_5, Parallel to the Test Section

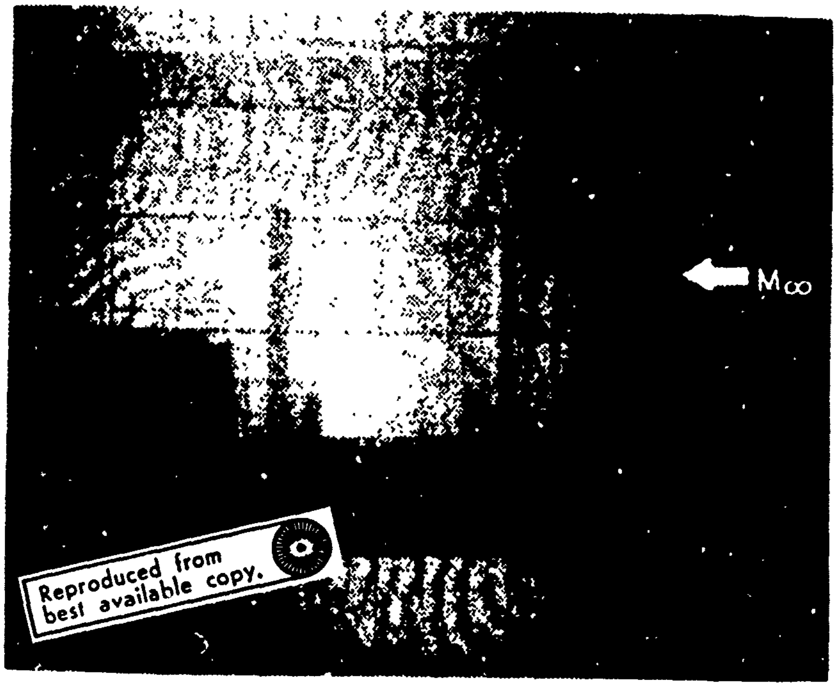

Figure 23. Interferogram Obtained in the Total Flow Method with the Clear Plexiglas Fin Model at 0° Rotation, Mach 2.84 and a .0015 inches Horizontal Translation of the Diffuser Plate Parallel to the Test Section

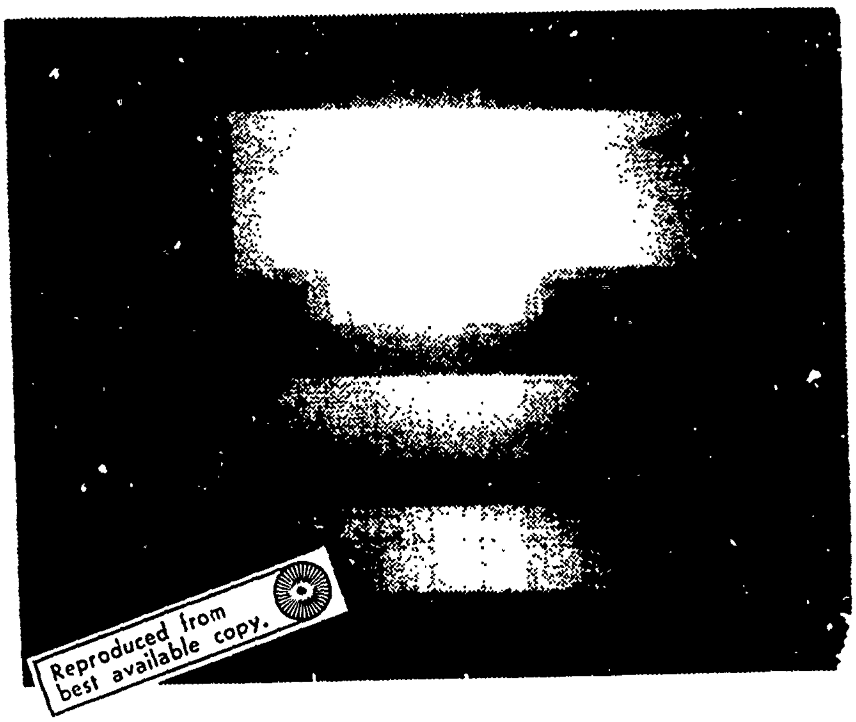

Figure 24. Interferogram Obtained in the Total Flow Method with the Clear Plexiglas Fin Model at 0° Rotation, Mach 2.84 and a .0045 Vertical Translation of the Diffuser Plate Parallel to the Test Section

Figure 25(a). Illustration of the Shock Network Around the Fin at Mach 2.84 with a 90° Model Rotation Angle Using a Horizontal Knife Edge Schlierer System

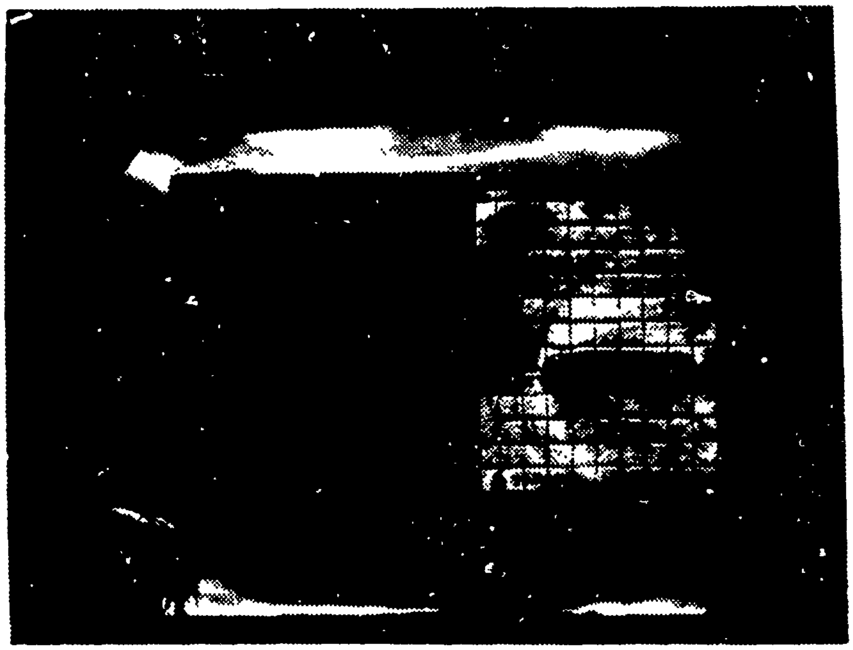

Figure 25(l). Illustration of the Shock Network Around the Fin at Mach 2.84 with a 90° Model Rotation Angle Using a Vertical Knife Edge Schlieren System

Figure 26. Illustration of the Model Flow Network at Mach 2.84, 0° Model Rotation and a Plate Vibration of ±.05 Angle of Attack Using a Schlieren System

Figure 27. Illustration of the Model Flow Network at Mach 2.84, 0° Model Rotation and No Plate Vibration Using a Schlieren System

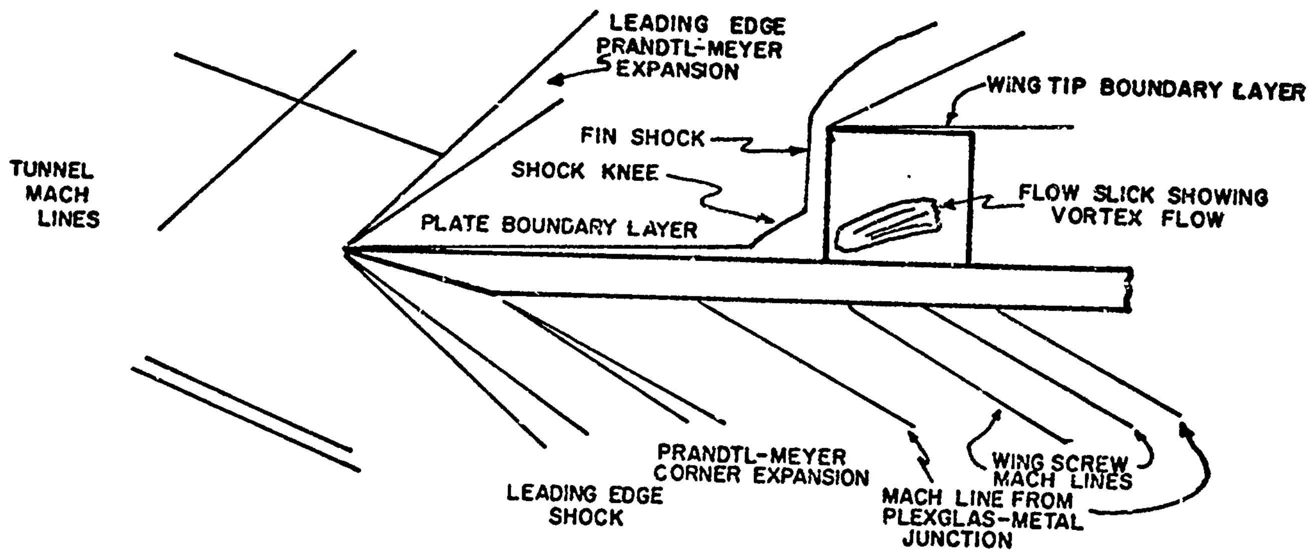

Figure 28. Schematic of the Flow Observed in the Schlieren Photographs

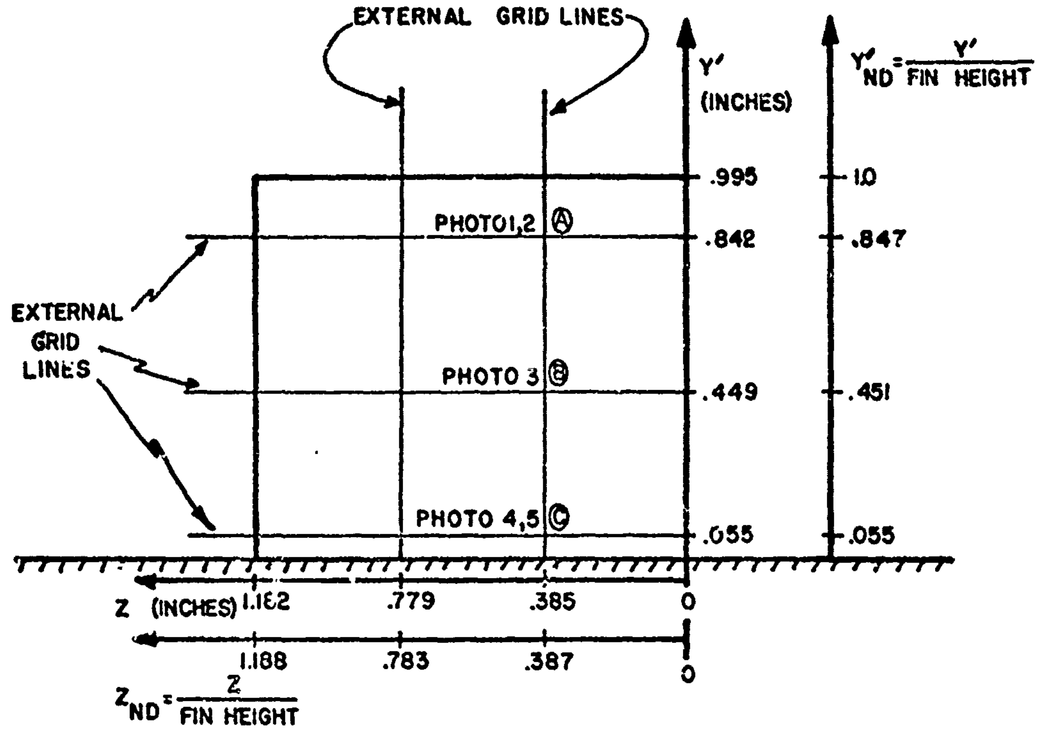

Figure 29. Schematic of the Fin at 0° Rotation Showing the Locations of the External Grid Lines and of the Interferogram Photographic Points

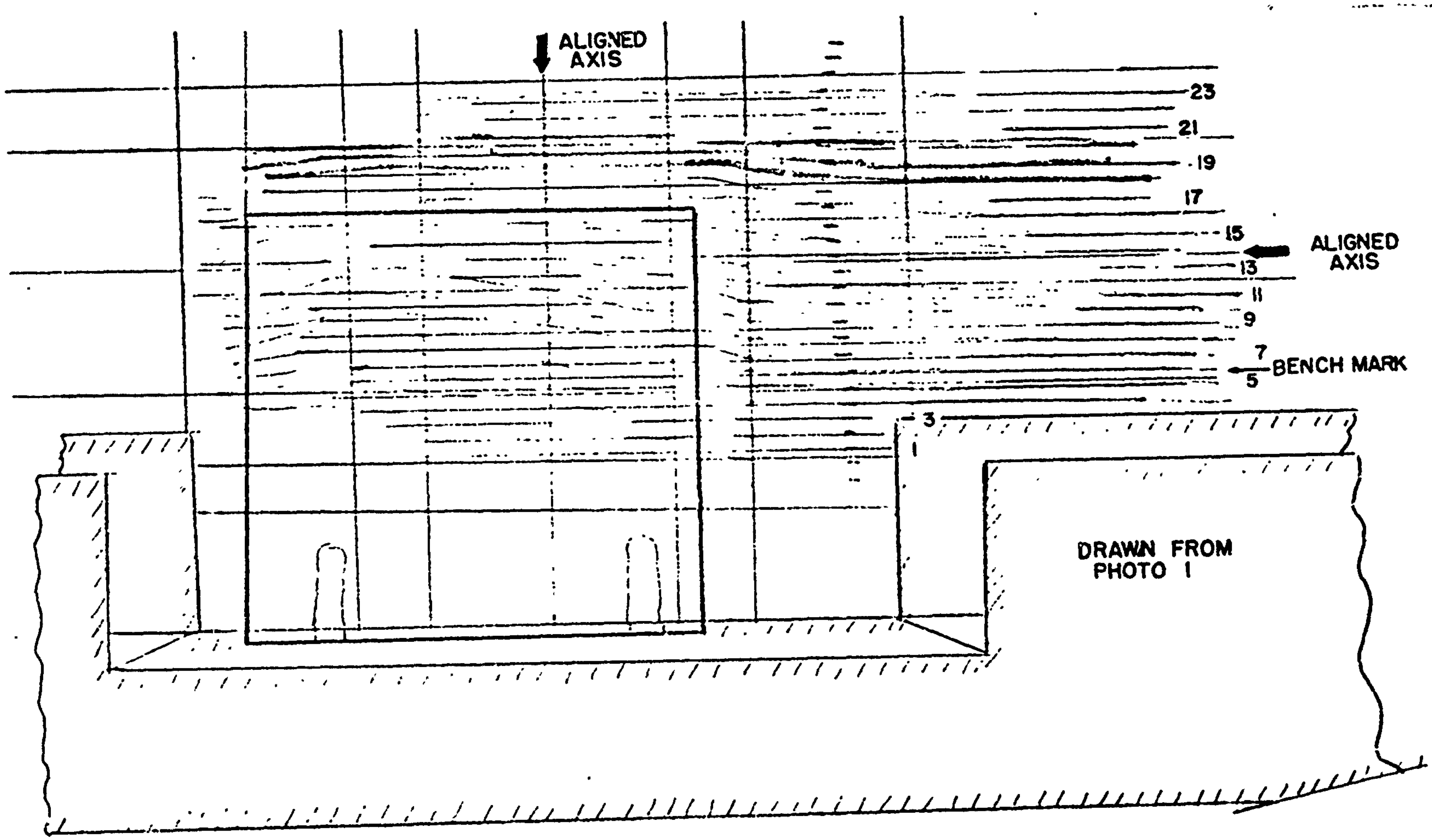

Figure 30. Actual Drawing and Data Reduction of Interferogram Photograph 1 Aligned at Z = 0.387, Y' = 0.847 for Mach 2.84 and 0° Model Rotation Angle

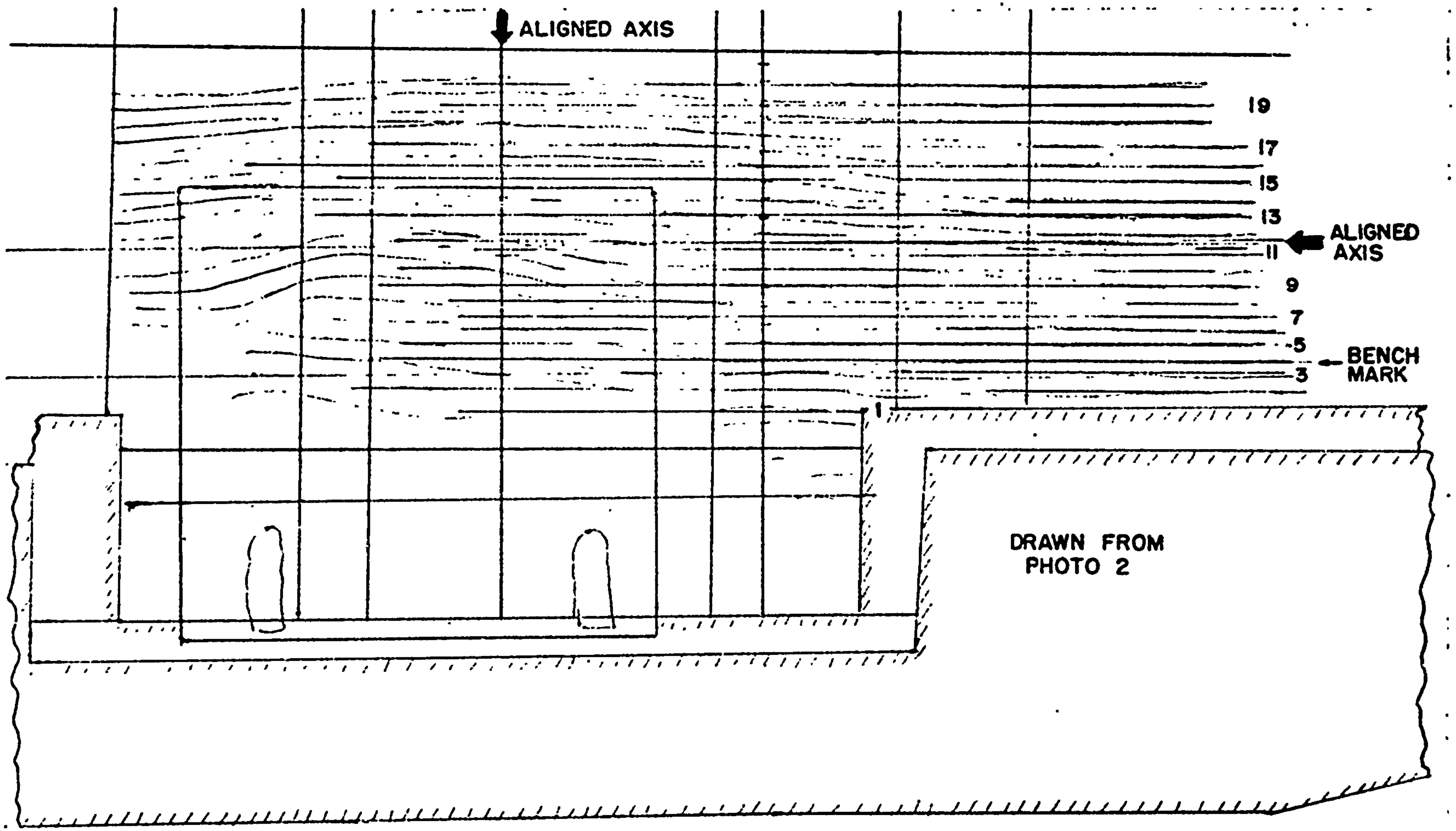

Figure 31. Actual Drawing and Data Reduction of Interferogram Photograph 2 Aligned at Z = 0.387, Y' = 0.847 for Mach 2.84 and 0° Model Rotation Angle

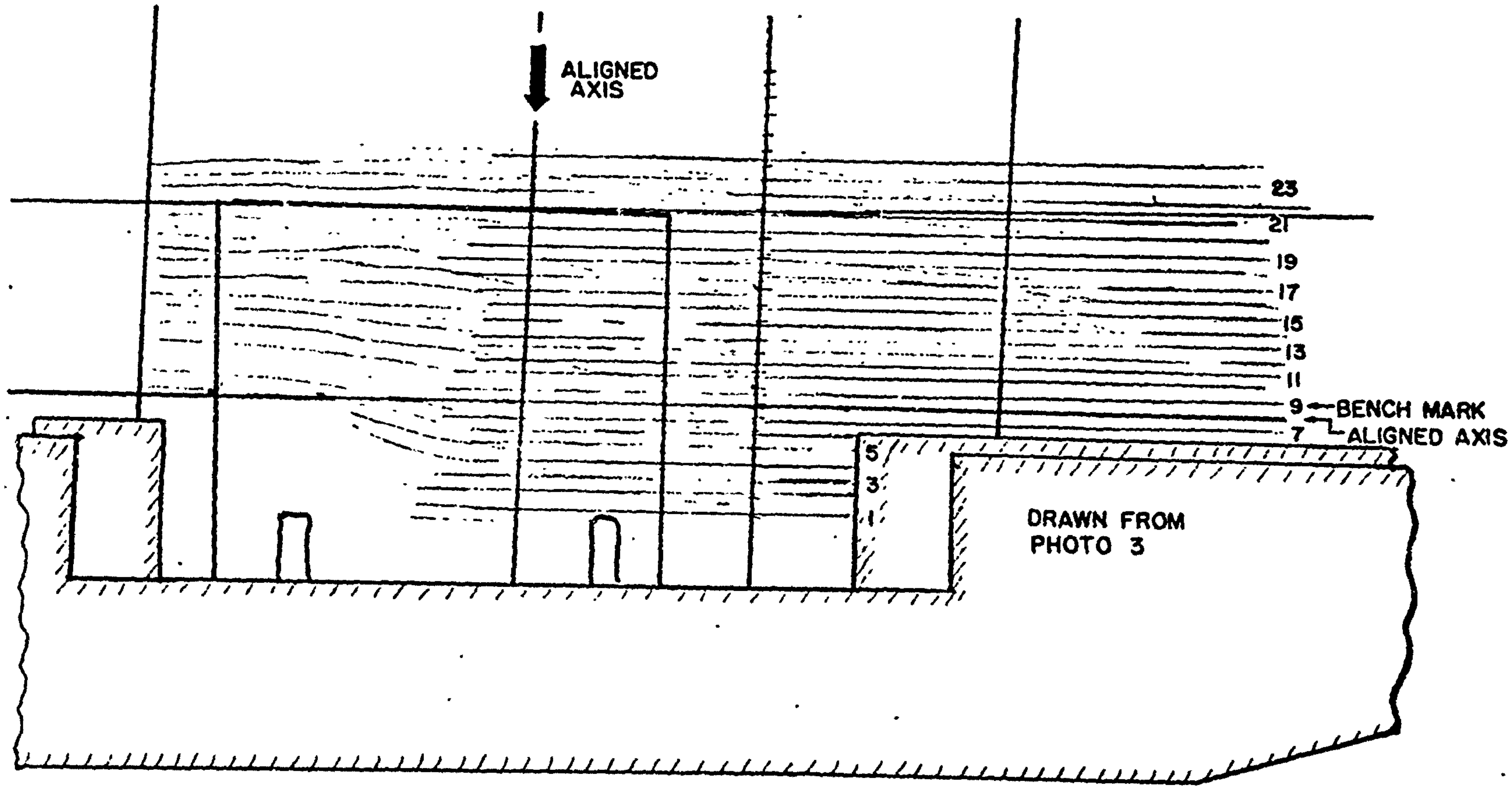

Figure 32. Actual Drawing and Data Reduction of Interferogram Photograph 3 Aligned at Z = 0.381, Y' = 0.451 for Mach 2.84 and 0° Model Rotation Angle

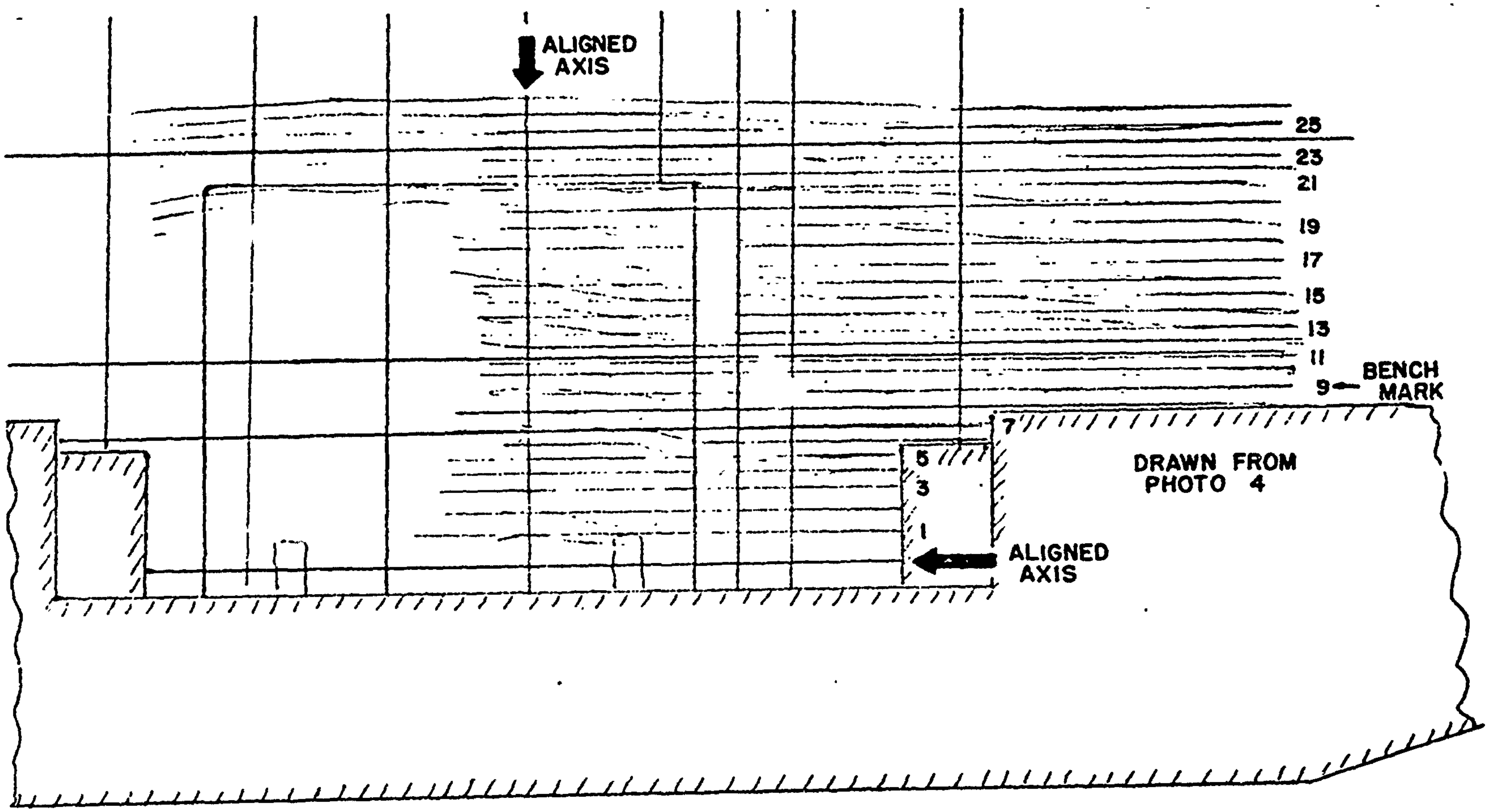

Figure 33. Actual Drawing and Data Reduction of Interferogram Photograph 4 Aligned at Z = 0.387, Y' = 0.055 for Mach 2.84 and 0° Model Rotation Angle

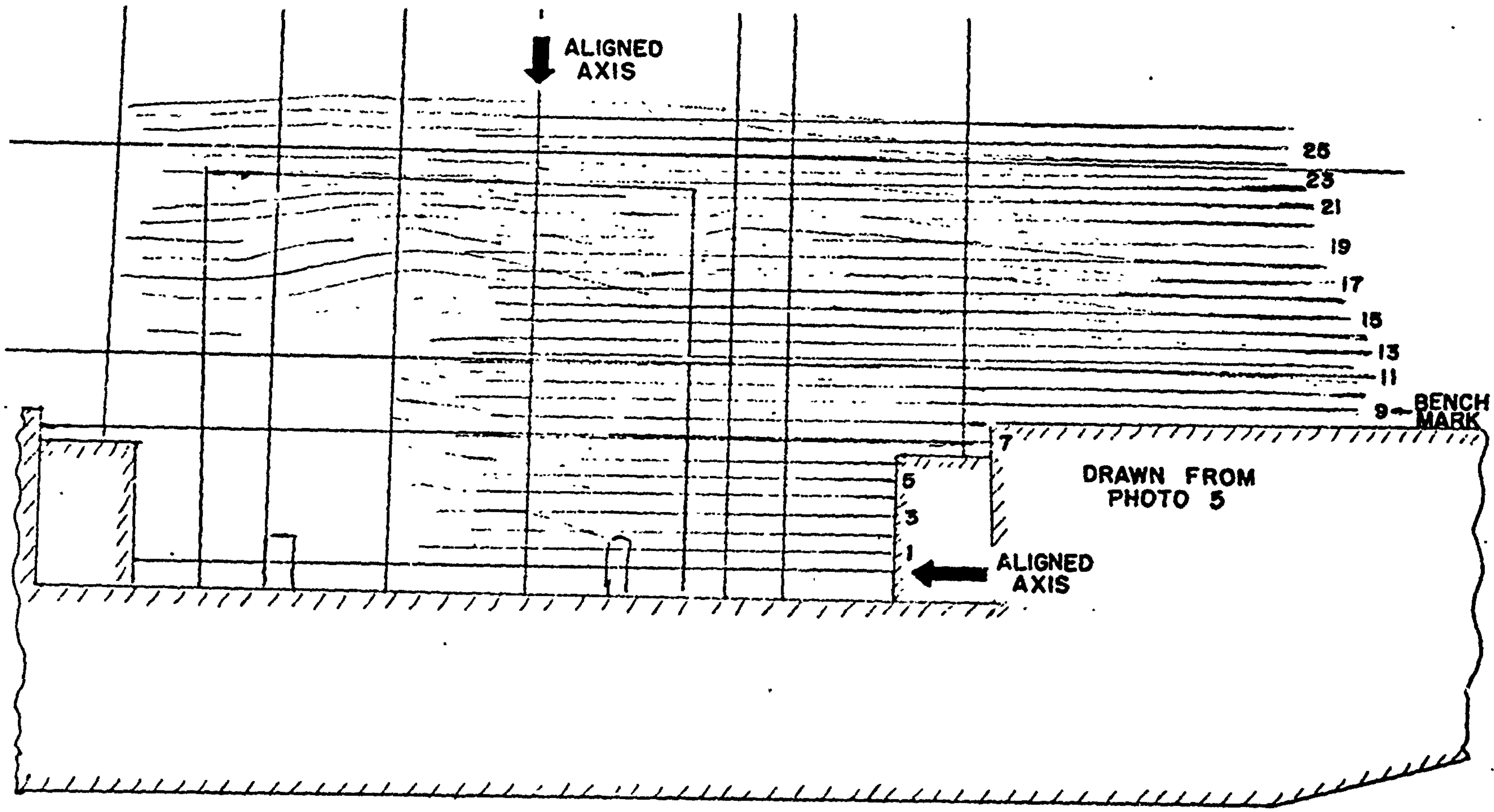

Figure 34. Actual Drawing and Data Reduction of Interferogram Photograph 5 Aligned at Z = 0.387, Y' = 0.055 for Mach 2.84 and 0° Model Rotation Angle

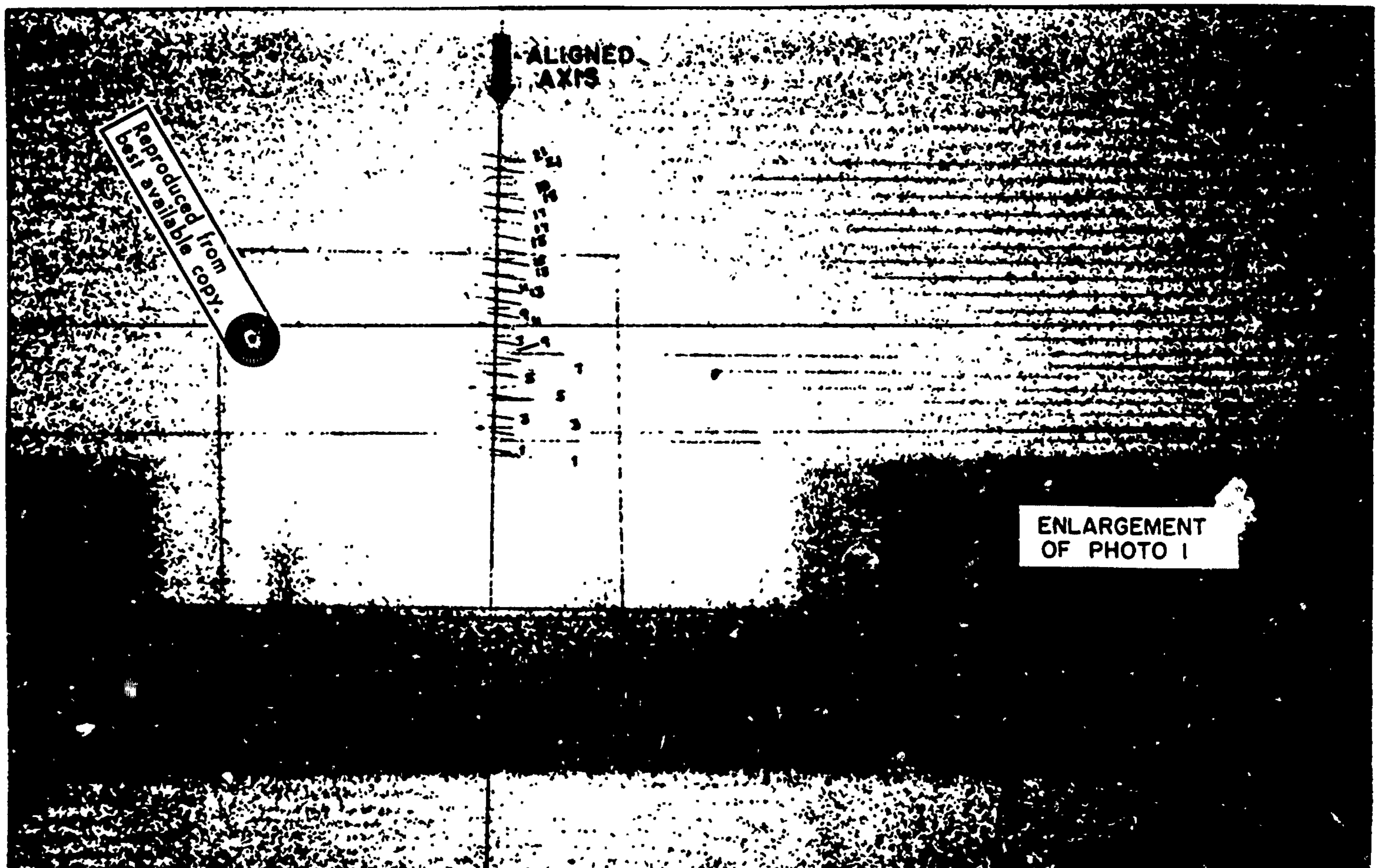

Figure 35. Actual Enlarged Photograph Used for the Data Reduction of Interferogram Photograph 1 Aligned at Z = 0.387, Y' = 0.847 for Mach 2.84 and 0° Model Rotation Angle

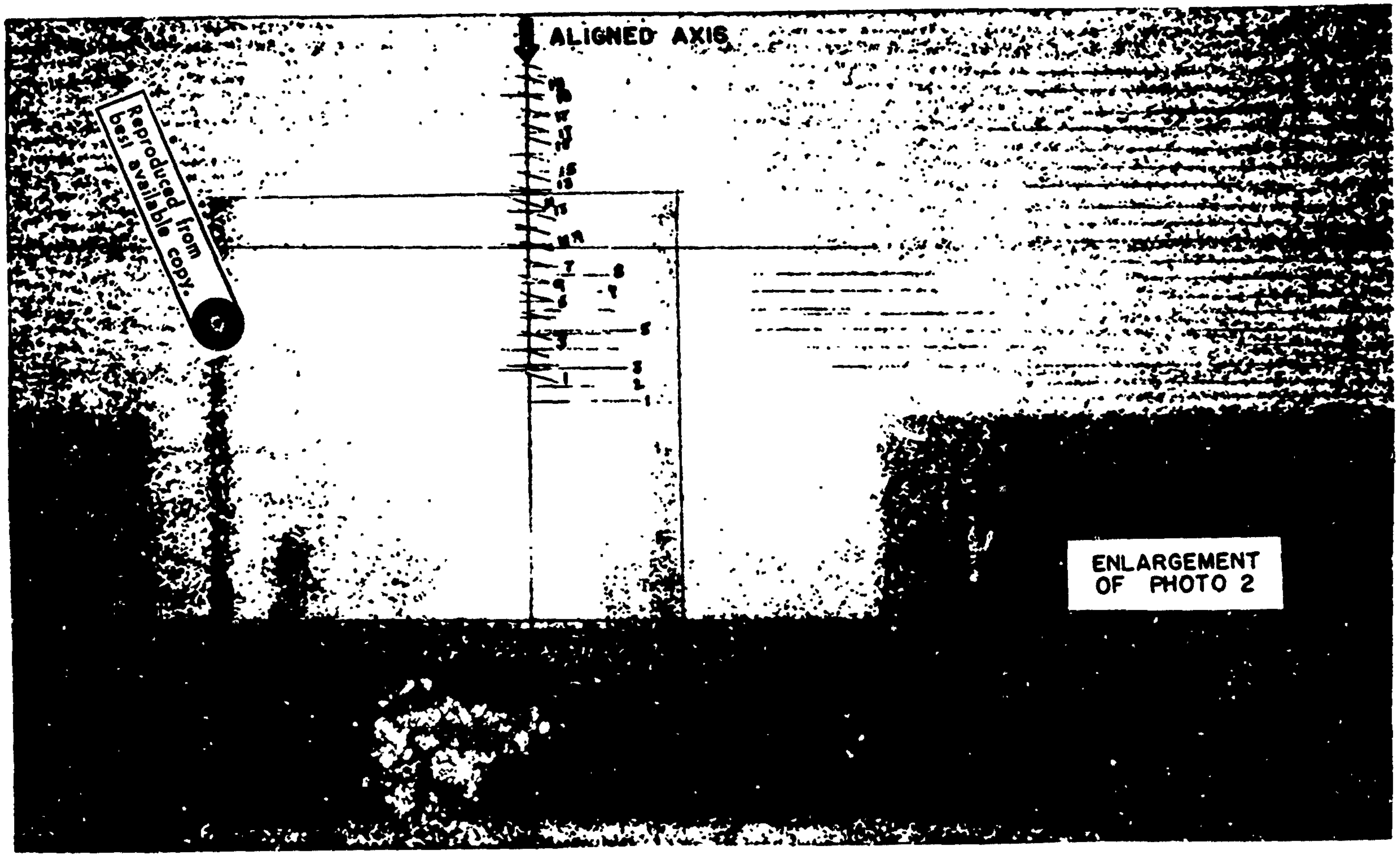

Figure 36. Actual Enlarged Photograph Used for the Data Reduction of Interferogram Photograph 2 Aligned at Z = 0.387, Y' = 0.847 for Mach 2.84 and 0° Model Rotation Angle

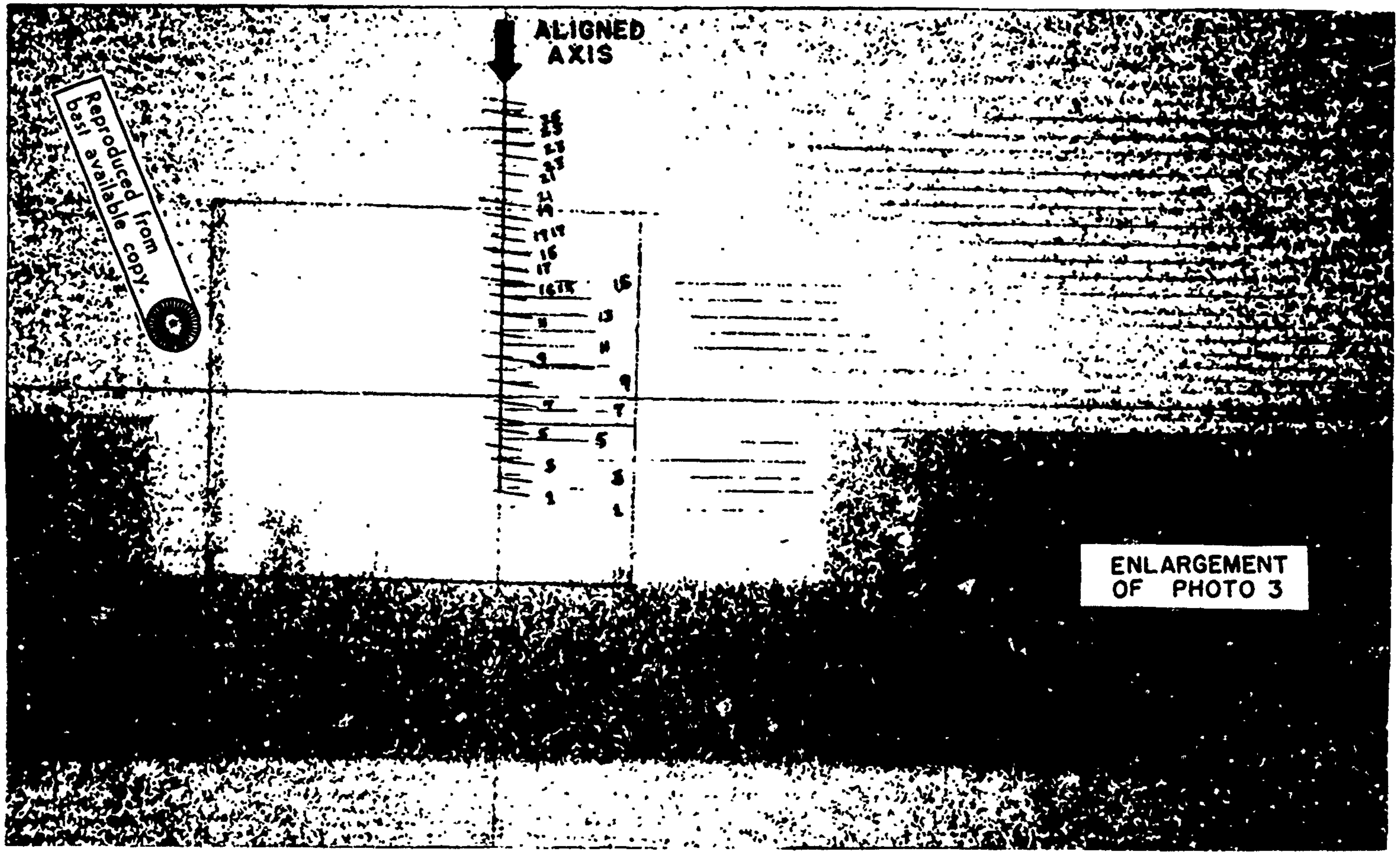

Figure 37. Actual Enlarged Photograph Used for the Data Reduction of Interferogram Photograph 3 Aligned at $Z = 0.387$, $Y' = 0.451$ for Mach 2.84 and 0 Model Rotation Angle

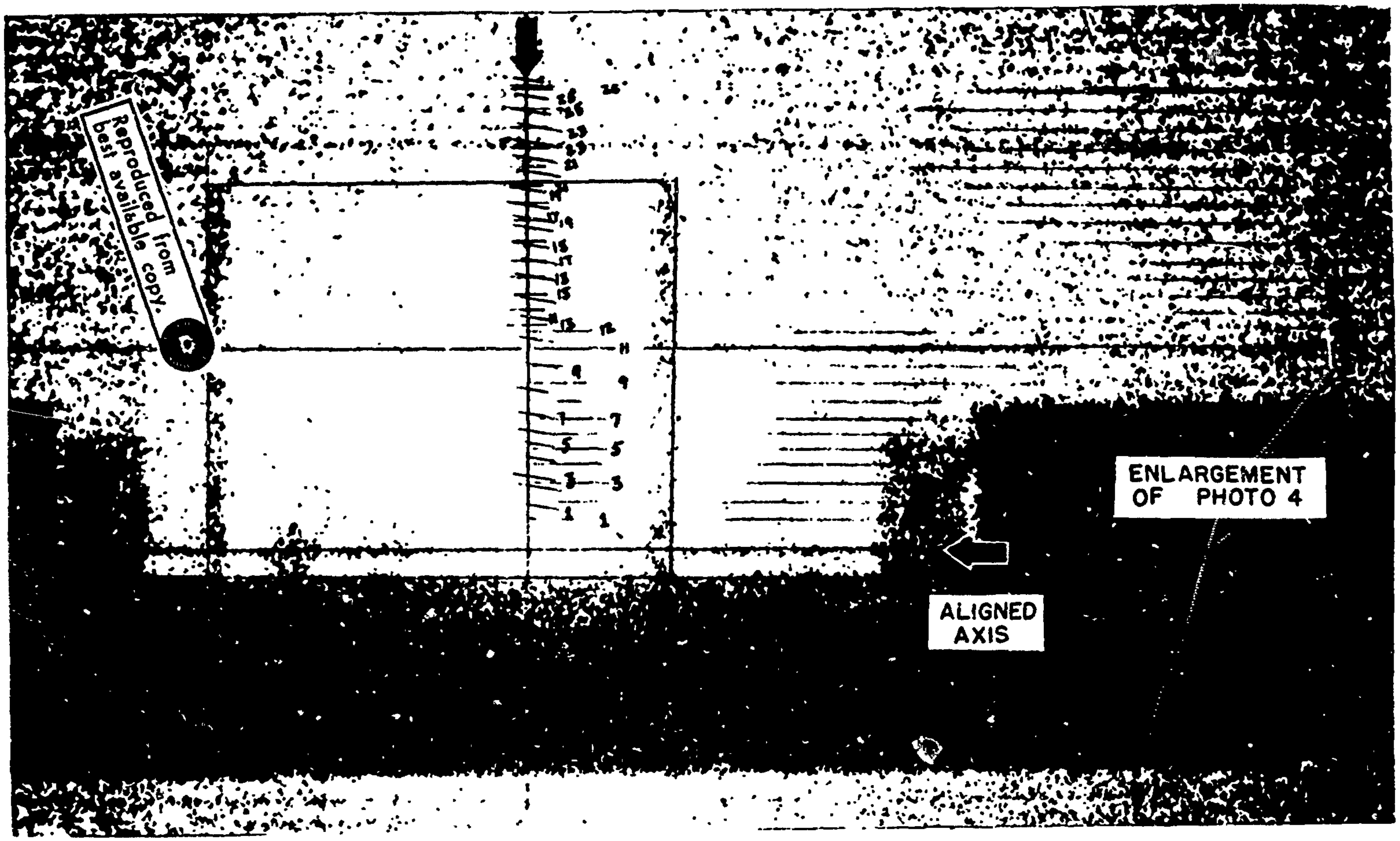

Figure 38. Actual Enlarged Photograph Used for the Data Reduction of Interferogram Photograph 4 Aligned at $Z = 0.387$, $Y' = 0.055$ for Mach 2.84 and 0° Model Rotation Angle

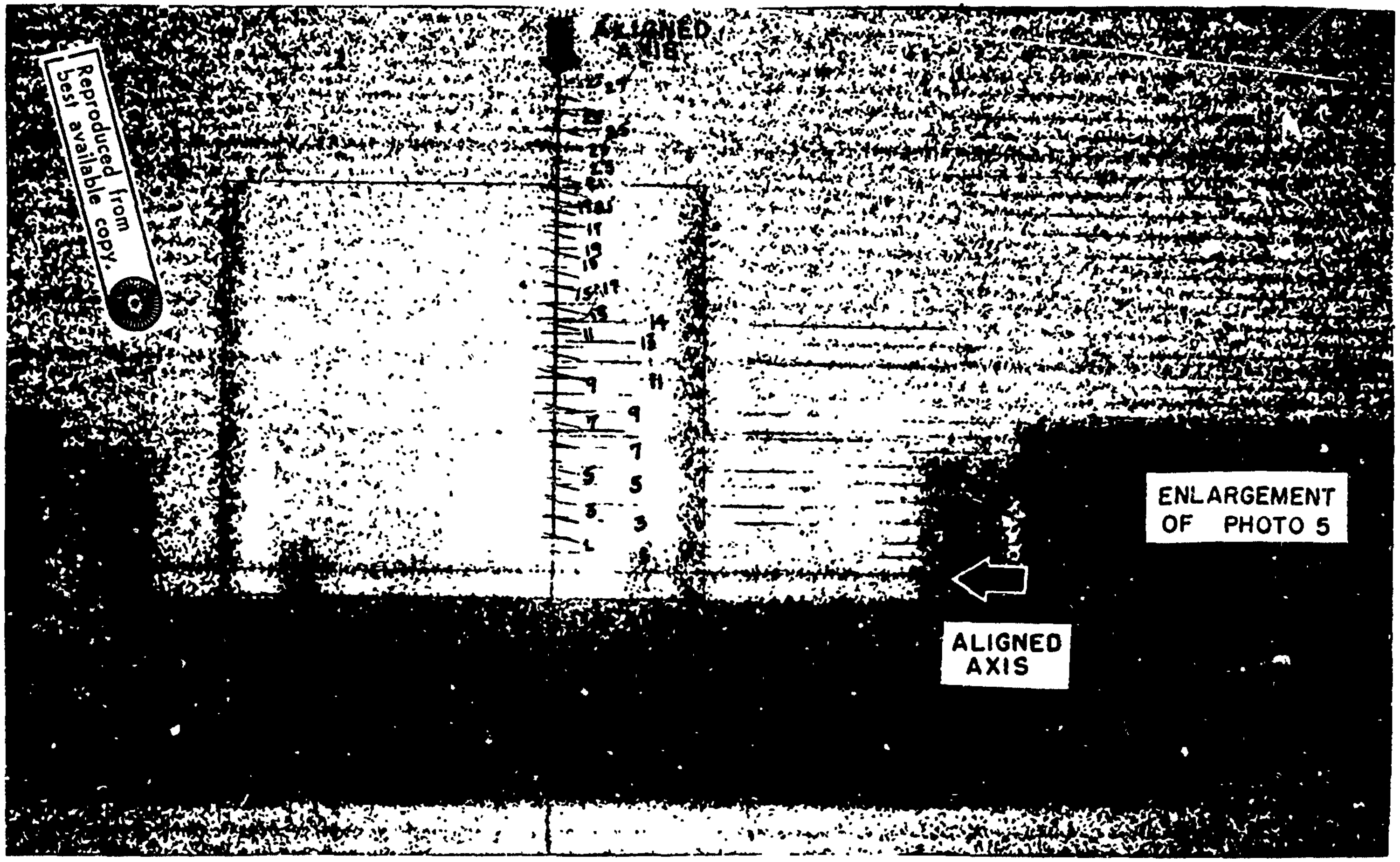

Figure 39. Actual Enlarged Photograph Used for the Data Reduction of Interferogram Photograph 5 Aligned at Z = 0.387, Y' = 0.055 for Mach 2.84 and 0° Model Rotation Angle

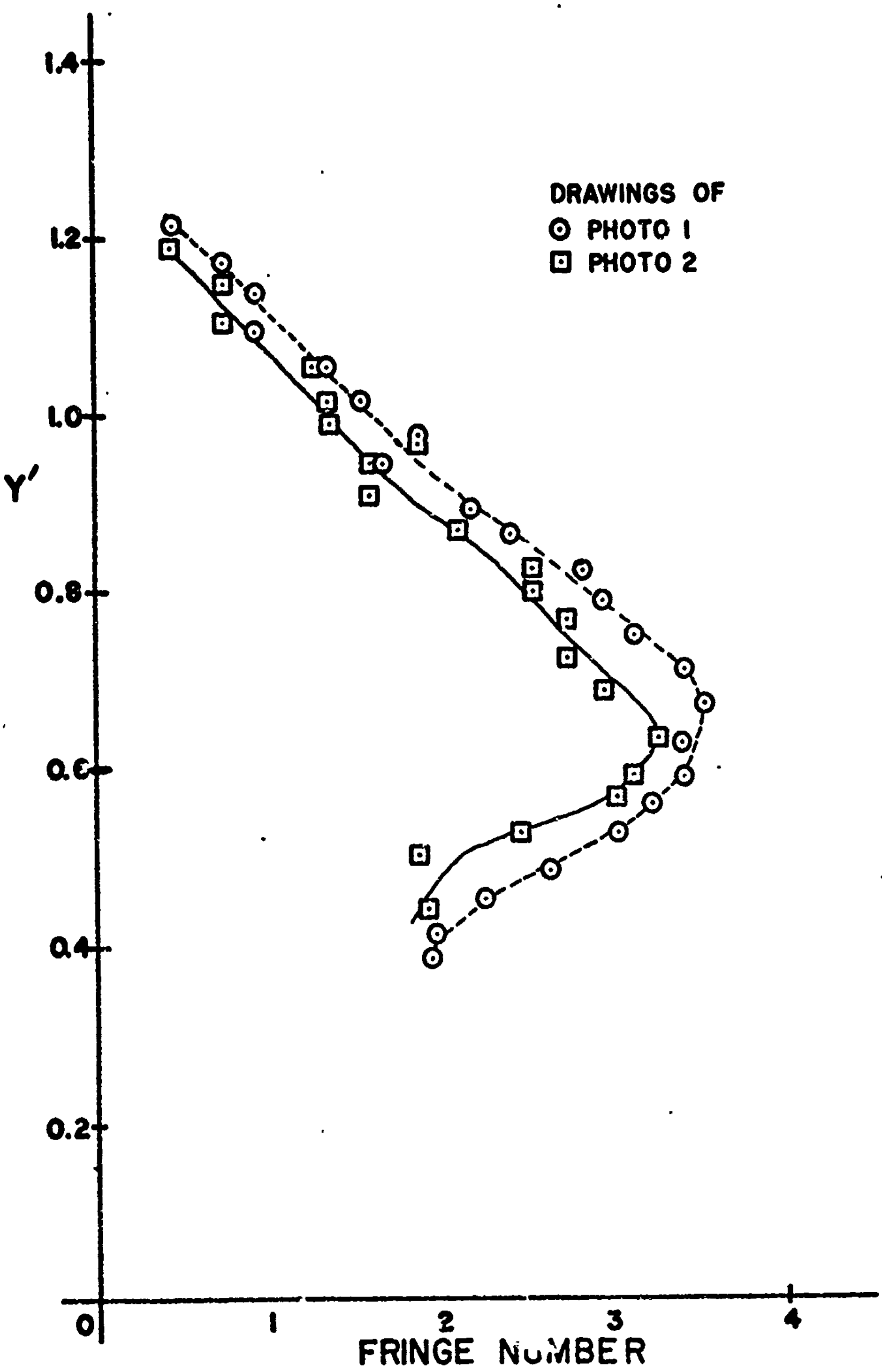

Figure 40. Comparison of Fringe Data Obtained from Drawings of Interferogram Photographs 1 and 2 Aligned at Y' = 0.847

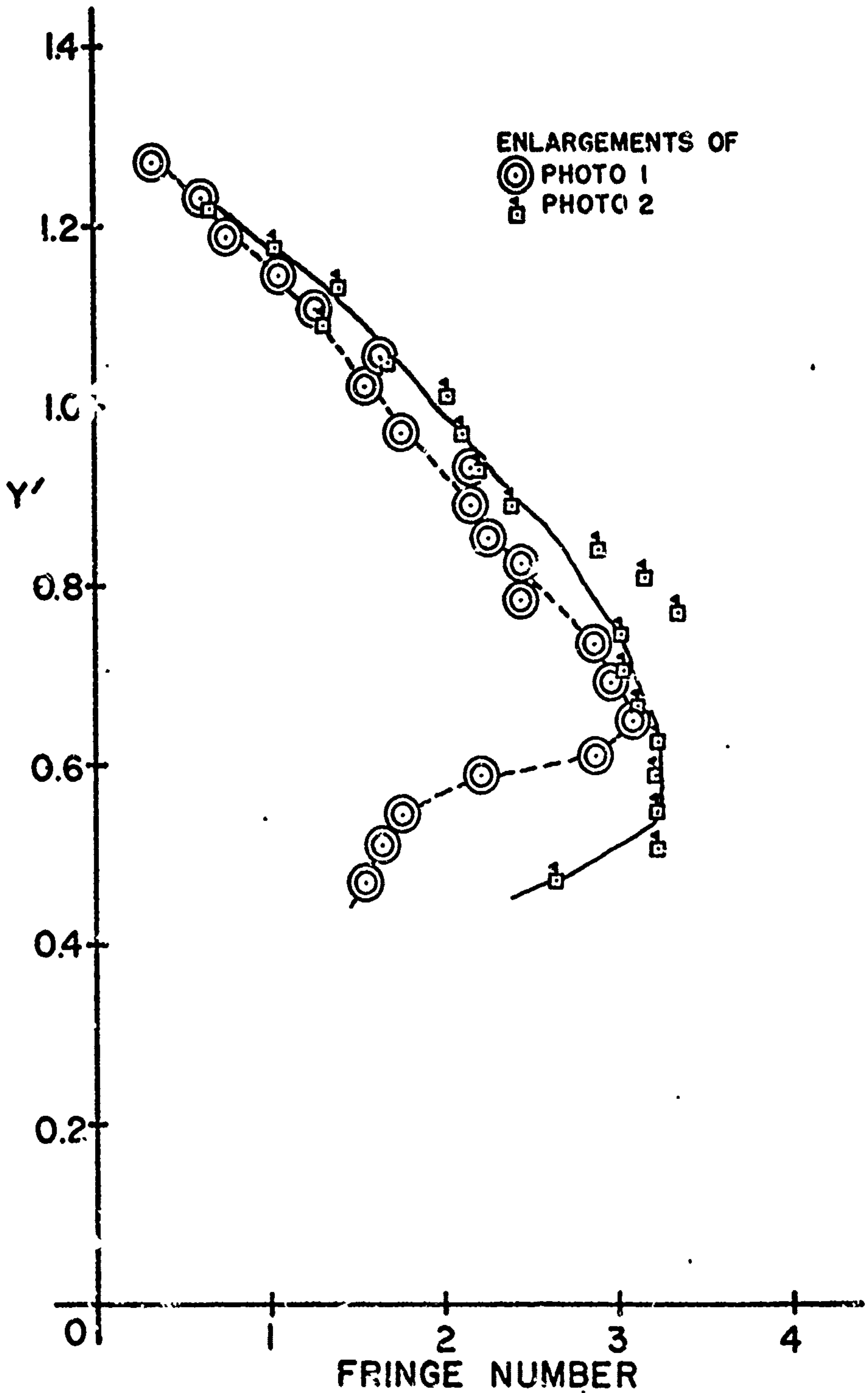

Figure 41. Comparison of Fringe Data Obtained from Photographic Enlargements of Interferogram Photographs 1 and 2 Aligned at Y' = 0.847

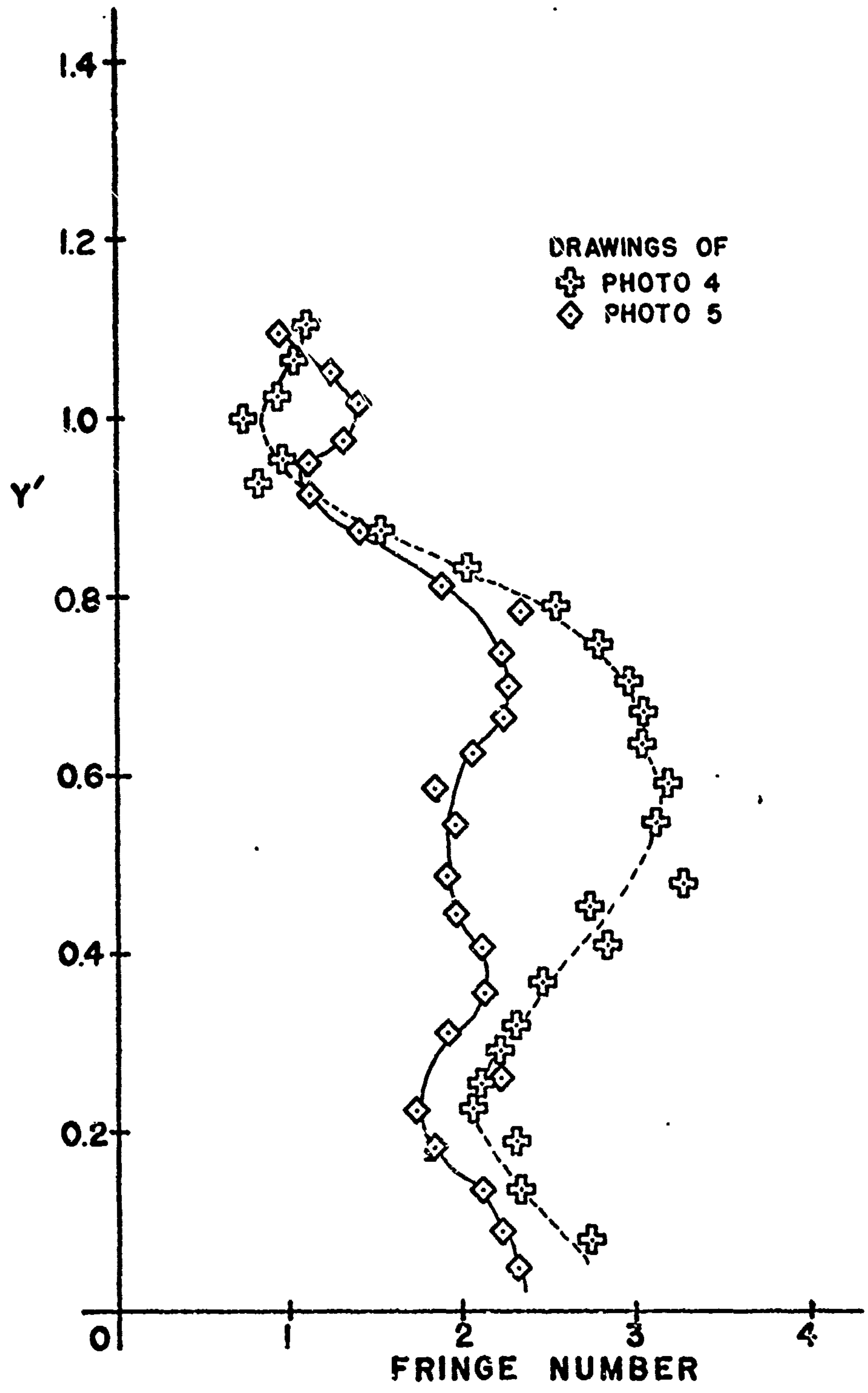

Figure 42. Comparison of Fringe Data Obtained from Drawings of Interferogram Photographs 4 and 5 Aligned at Y' = 0.055

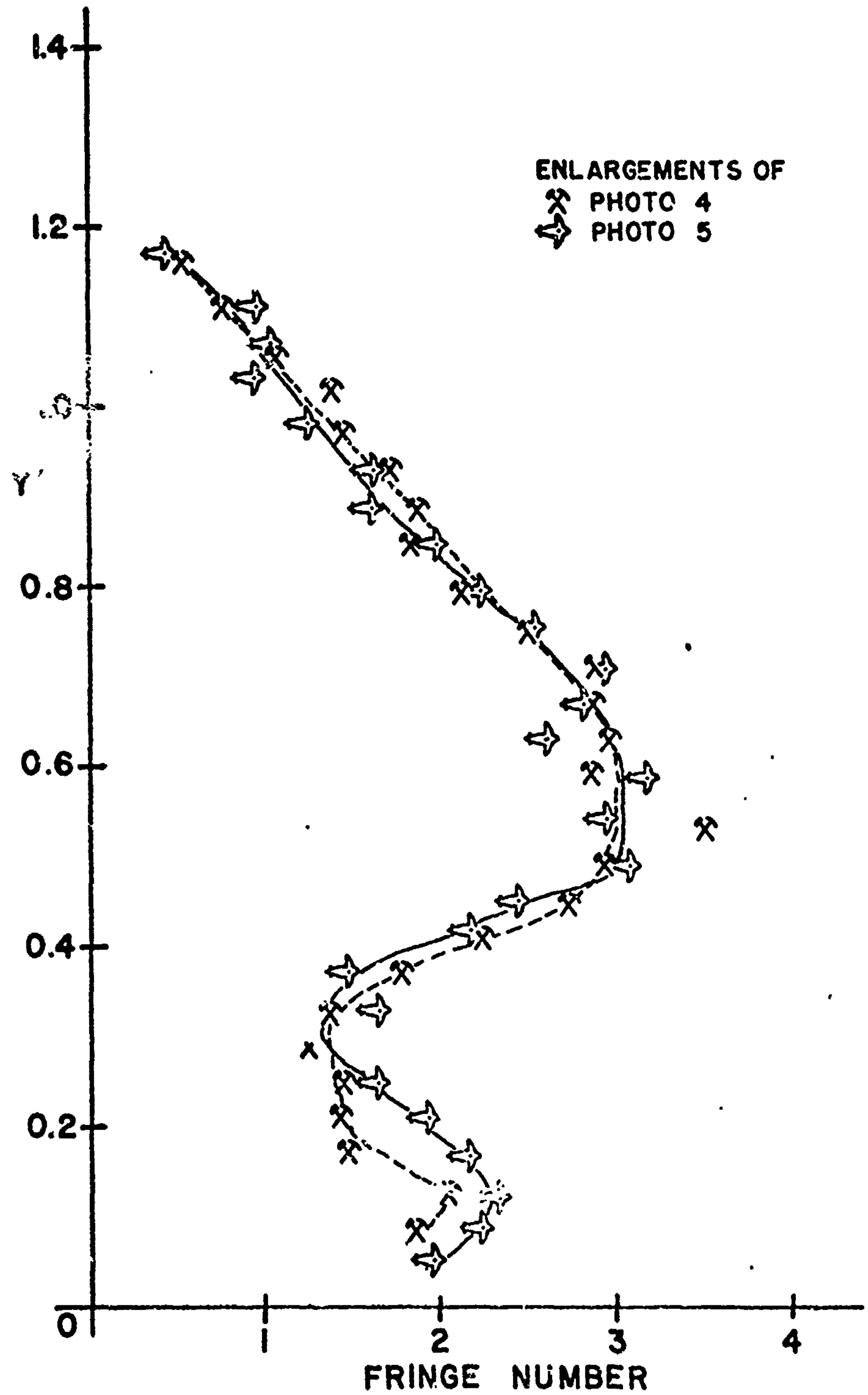

Figure 43. Comparison of Fringe Data Obtained from Photographic Enlargements of Interferogram Photographs 4 and 5 Aligned at Y' = 0.055

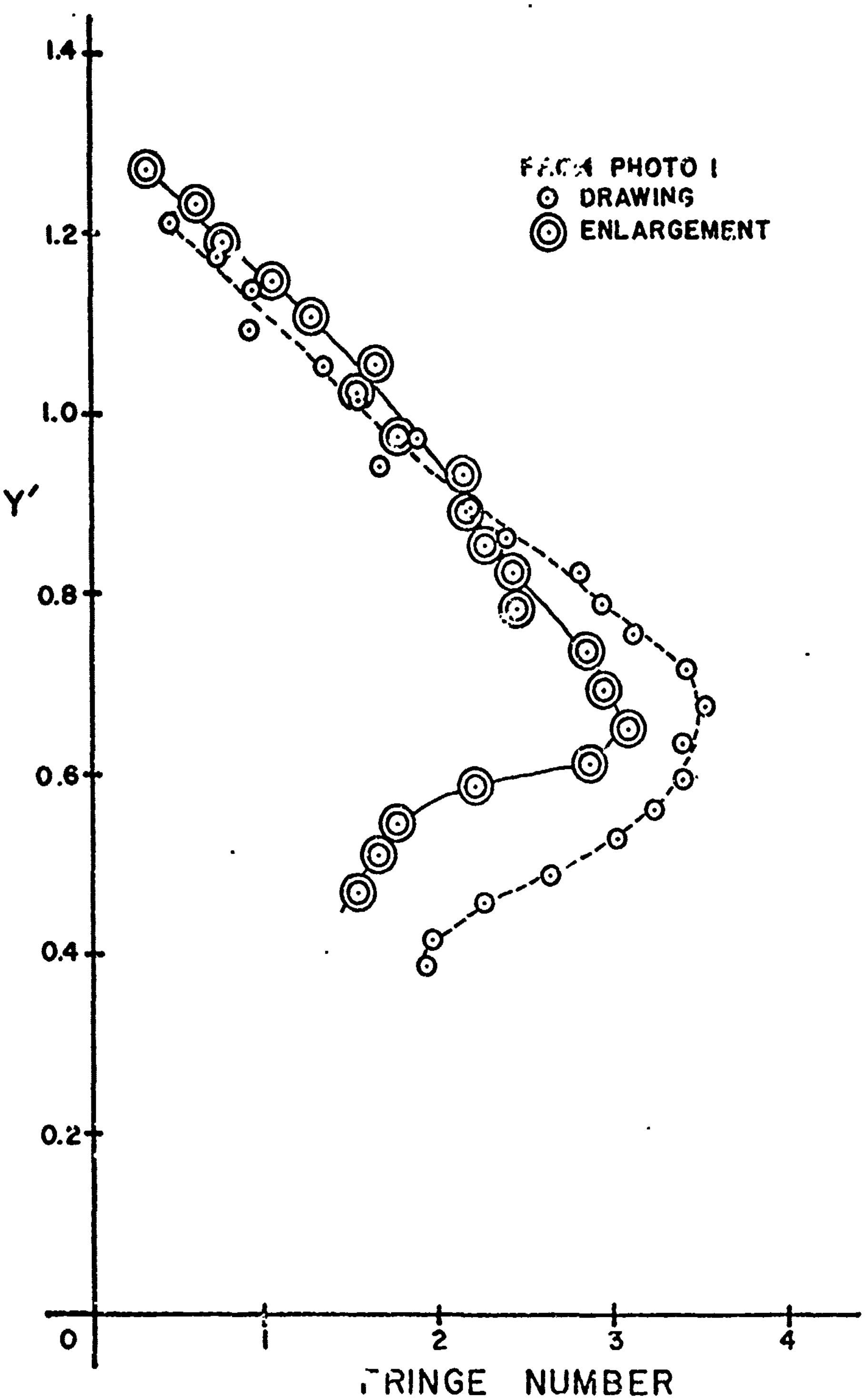

Figure 44. Comparison of Fringe Data Obtained from the Drawing and Photographic Enlargement of Interferogram Photograph 1 Aligned at Y' = 0.847

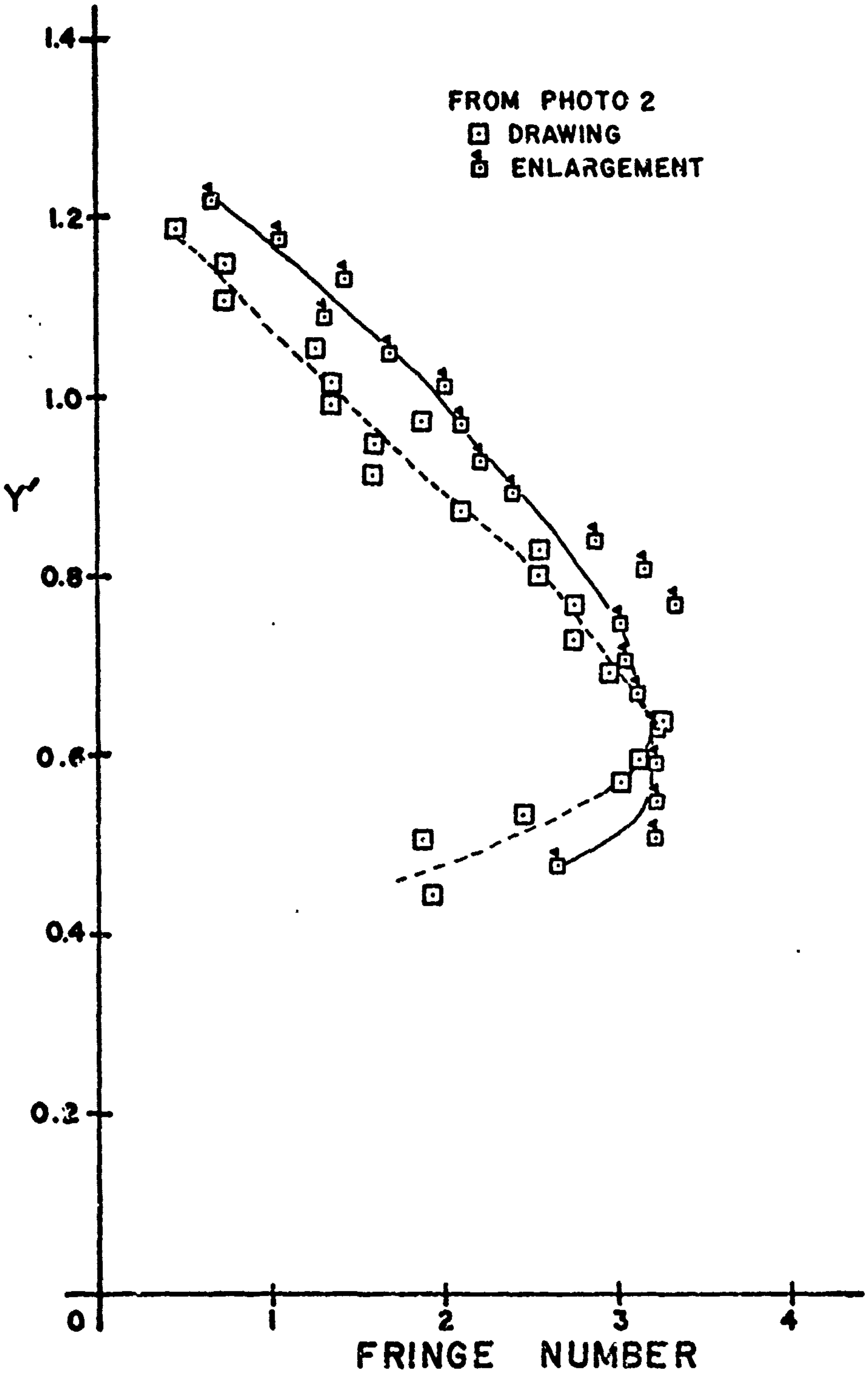

Figure 45. Comparison of Fringe Data Obtained from the Drawing and Photographic Enlargement of Interferogram Photograph 2 Aligned at Y' = 0.847

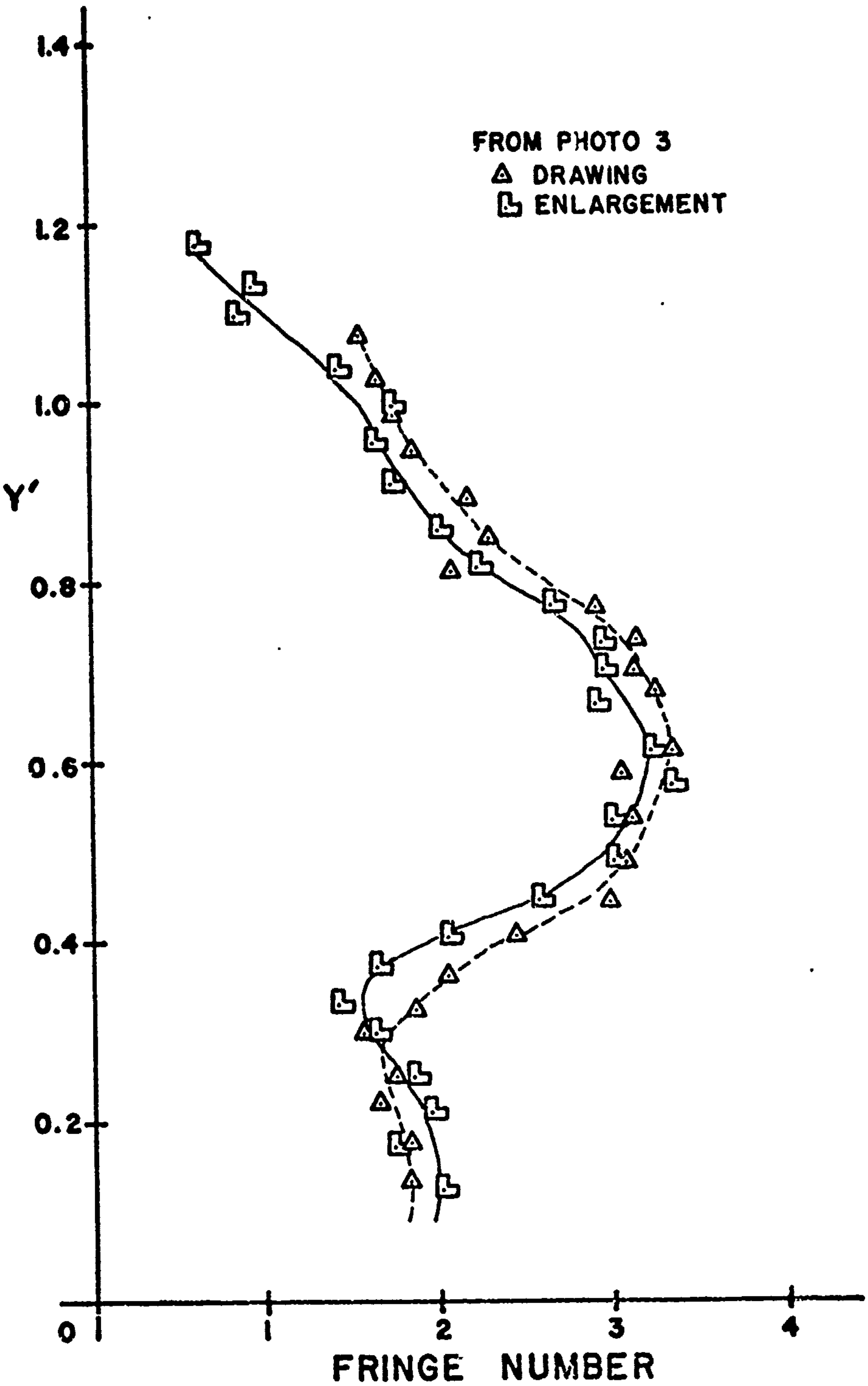

Figure 46. Comparison of Fringe Data Obtained from the Drawing and Photographic Enlargement of Interferogram Photograph 3 Aligned at Y' = 0.451

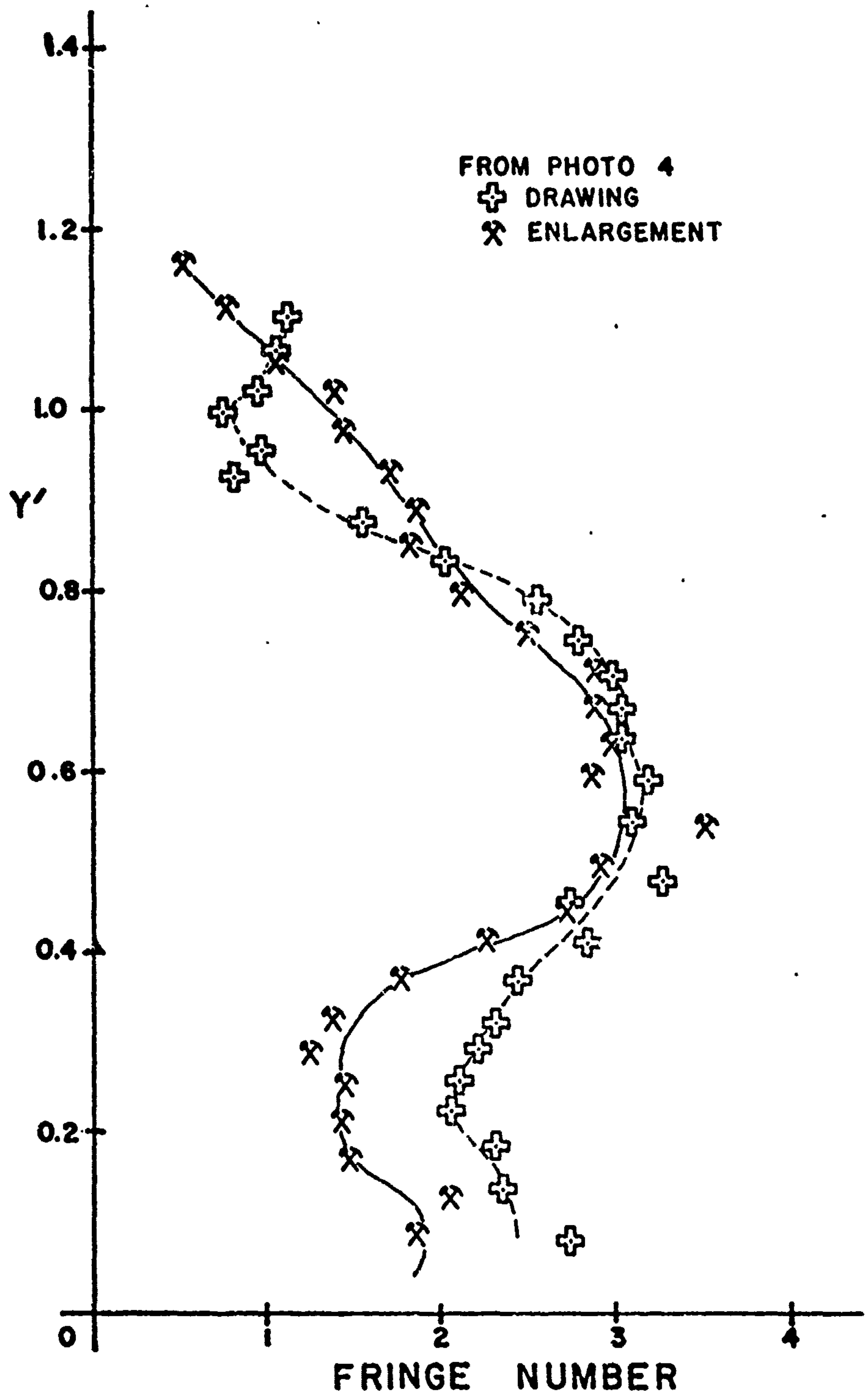

Figure 47. Comparison of Fringe Data Obtained from the Drawing and Photographic Enlargement of Interferogram Photograph 4 Aligned at Y' = 0.055

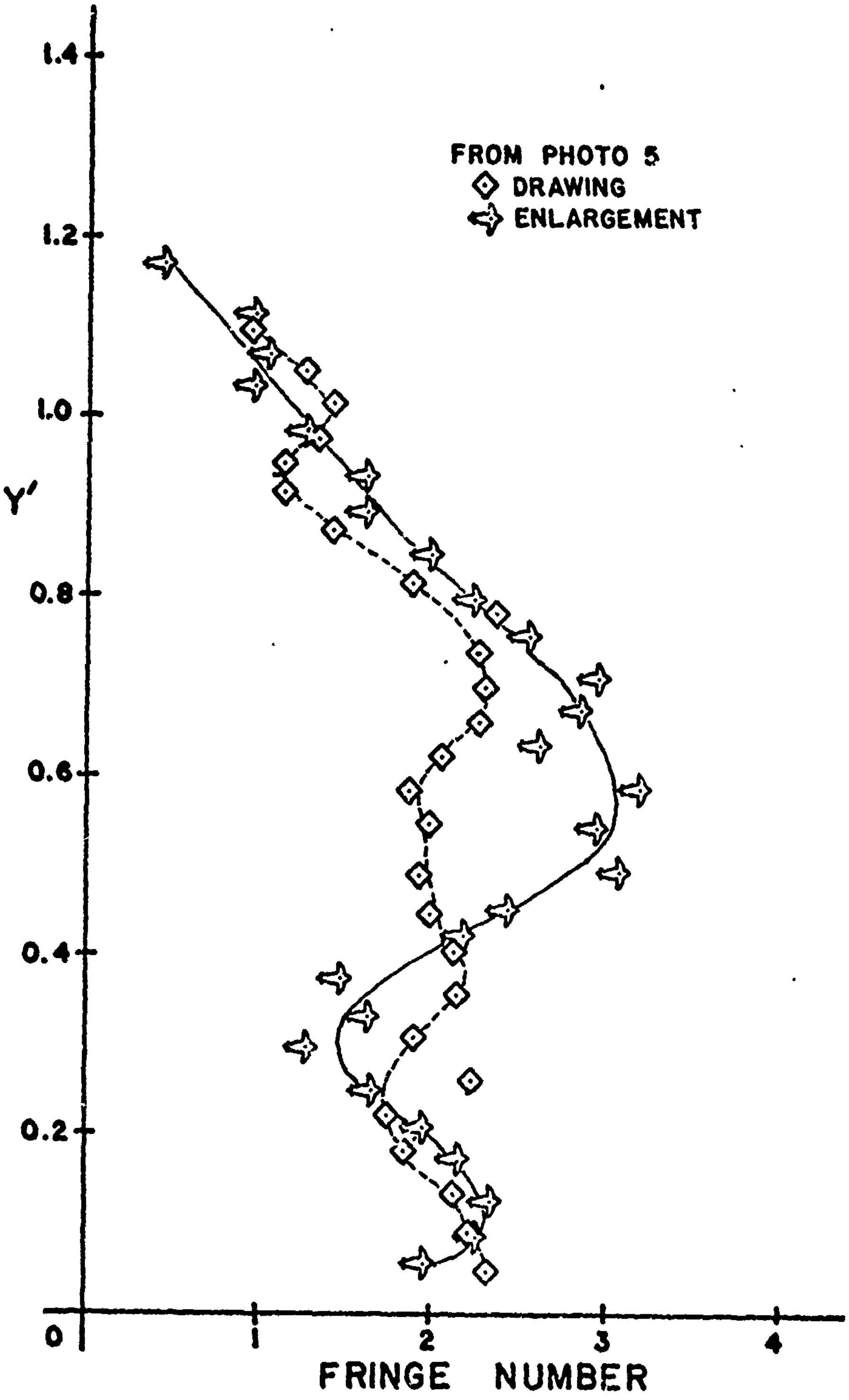

Figure 42. Comparison of Fringe Data Obtained from the Drawing and Photographic Enlargement of Interferogram Photograph 5 Aligned at Y' = 0.055

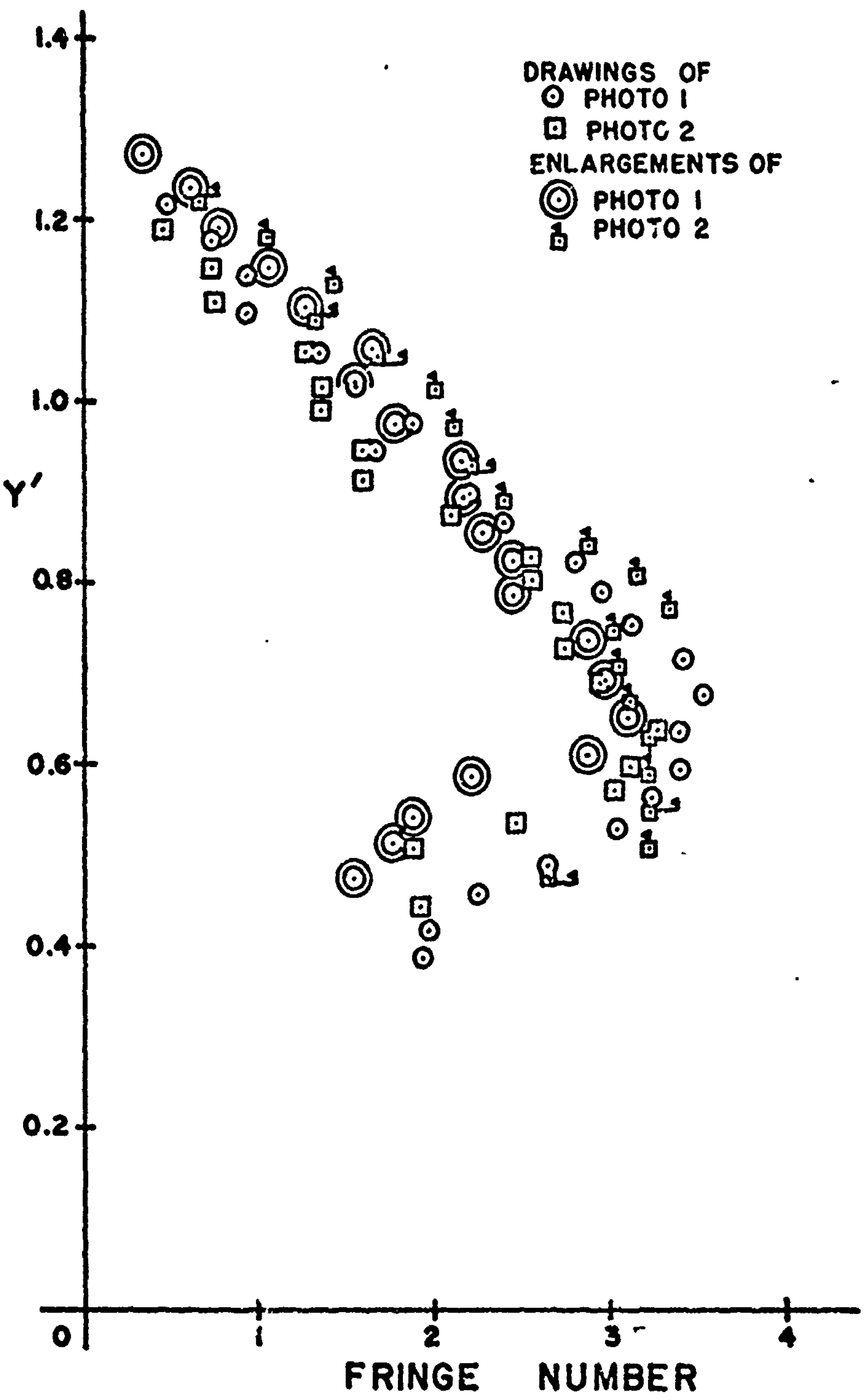

Figure 49. Comparison of Fringe Data Obtained from the Drawings and Photographic Enlargements of Interferogram Photographs 1 and 2 Aligned at Y' = 0.847

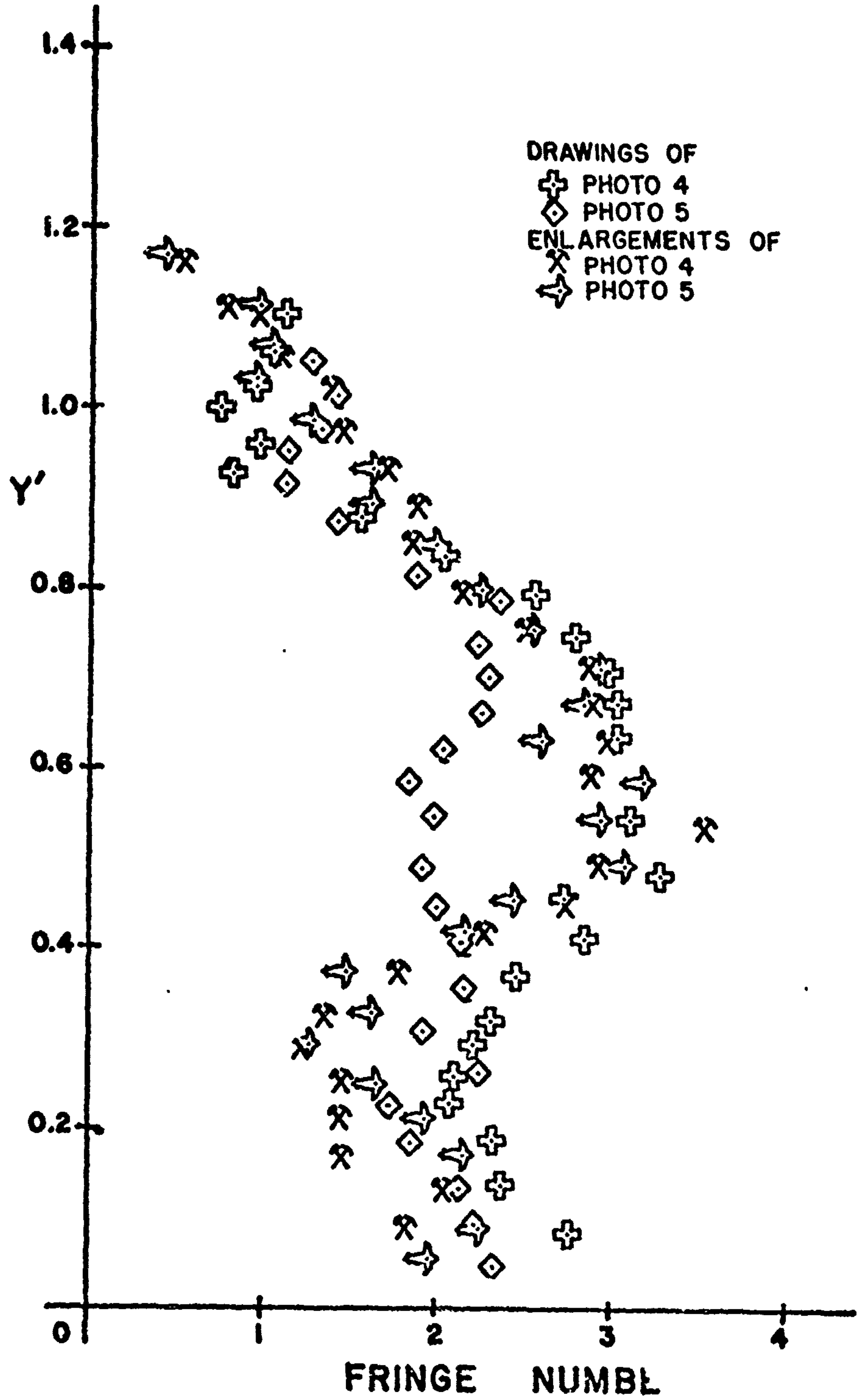

Figure 50. Comparison of Fringe Data Obtained from the Drawings and Photographic Enlargements of Interferogram Photographs 4 and 5 Aligned at Y' = 0.055

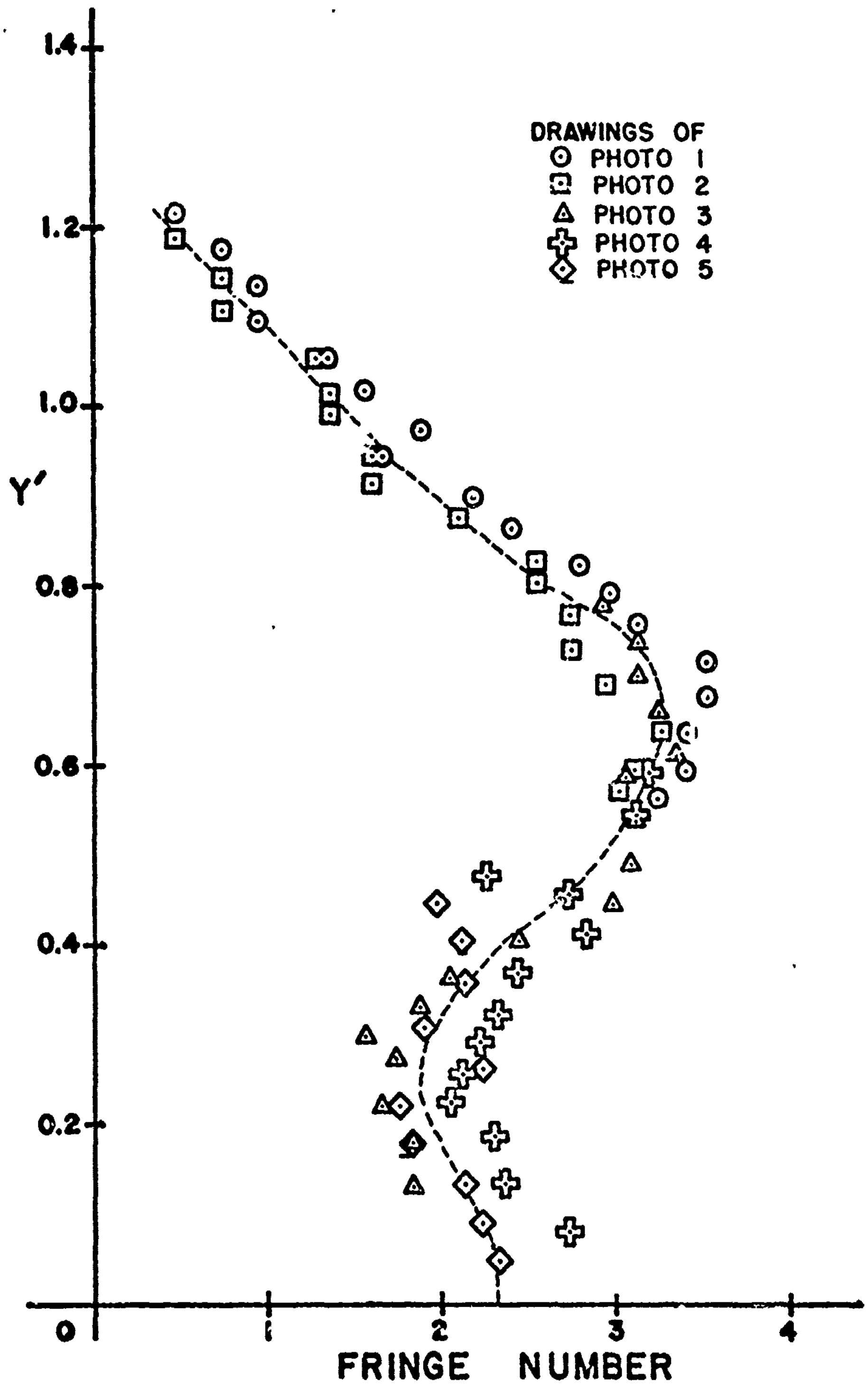

Figure 51. Fringe Number Across the Fin in the Z = 0.387 Plane for β = 0°, Mach 2.84 as Determined from the Drawings of the Interferogram Photographs

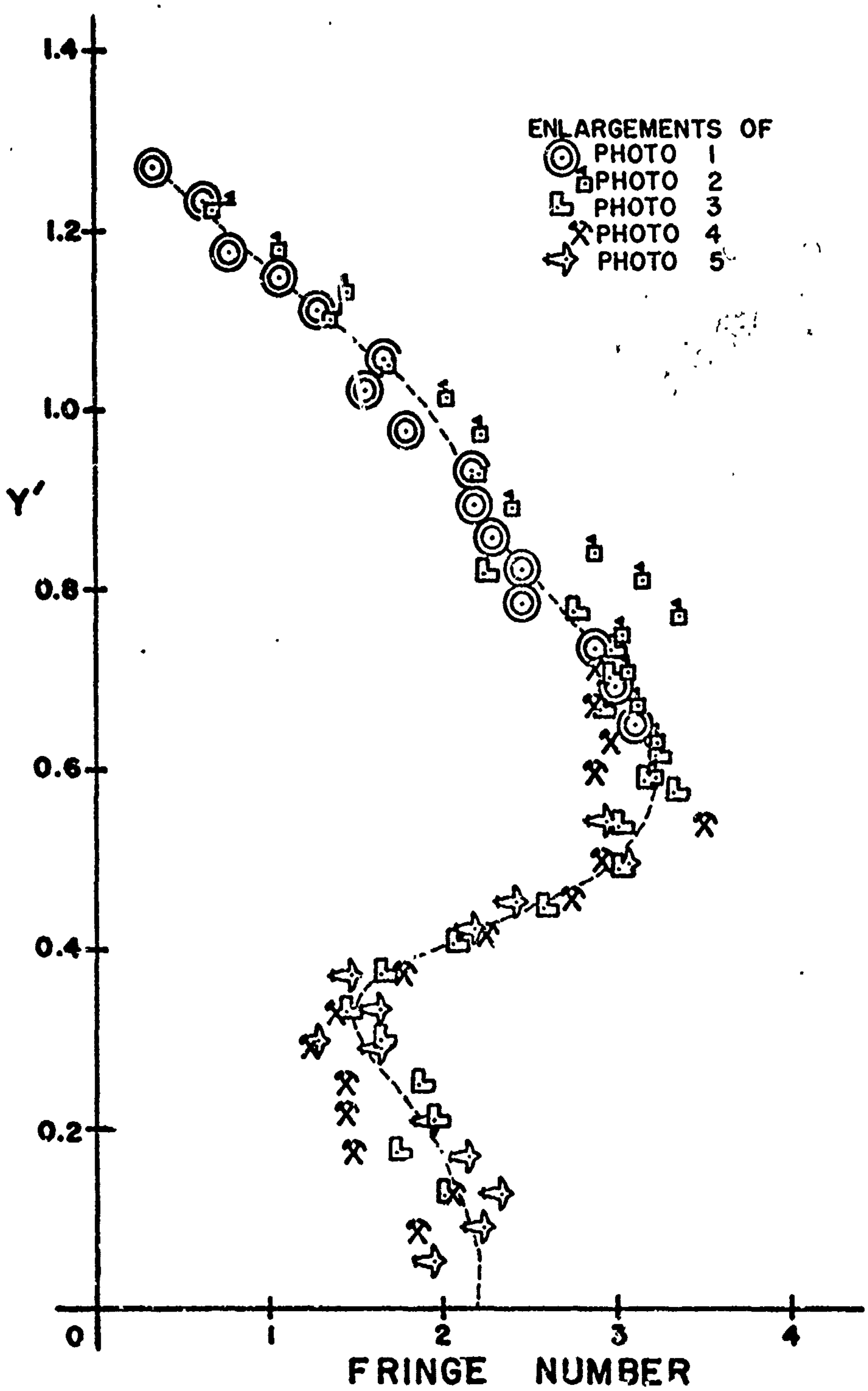

Figure 52. Fringe Number Across the Fin in the Z = 0.387 Plane for $\xi = 0°$, Mach 2.84 as Determined from the Photographic Enlargements of the Interferogram Photographs

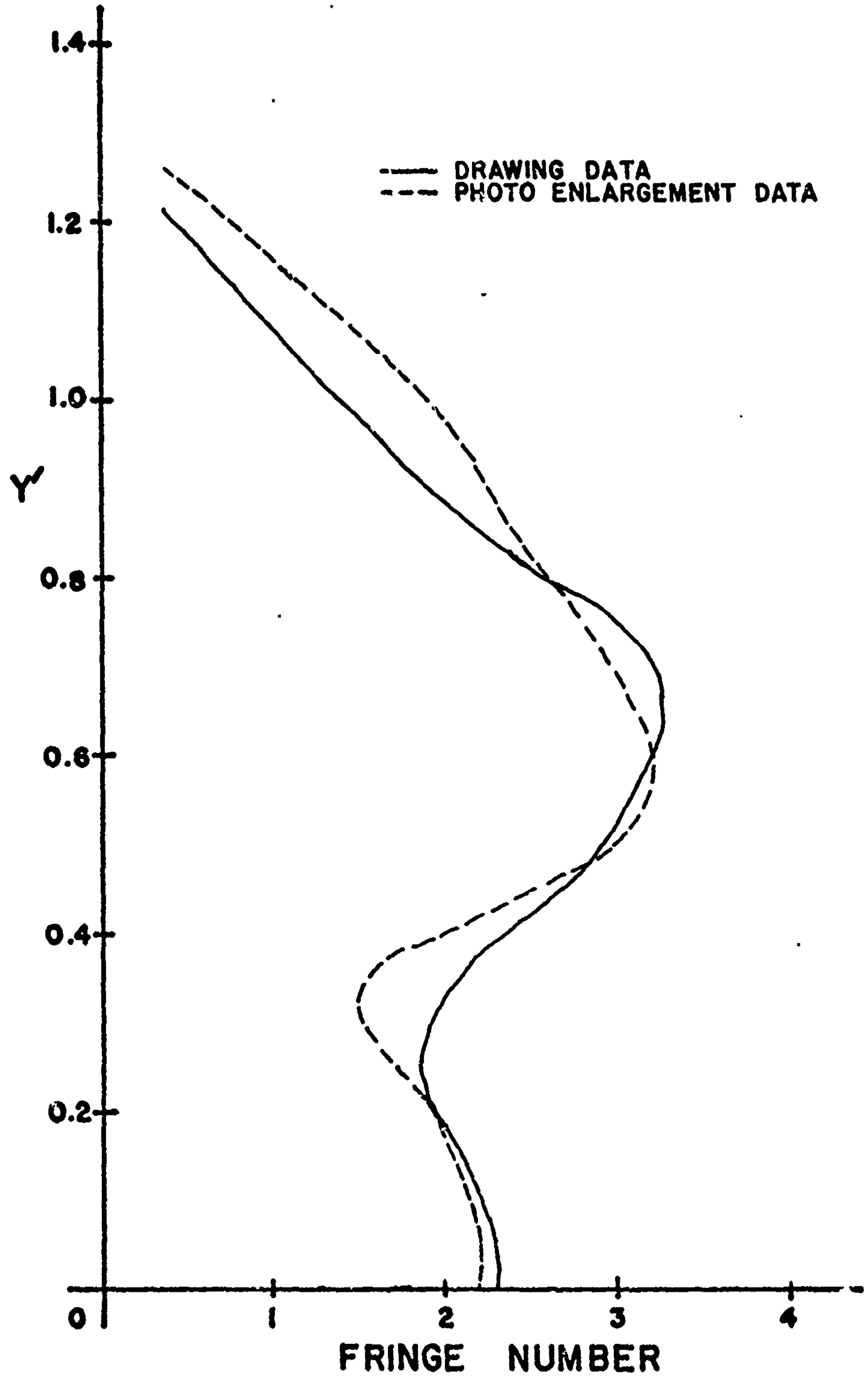

Figure 53. Comparison of the Fringe Numbers Across the Fin in the Z = 0.387 Plane for ξ = 0°, Mach 2.84 as Determined from the Drawings and Photographic Enlargements of the Interferogram Photographs

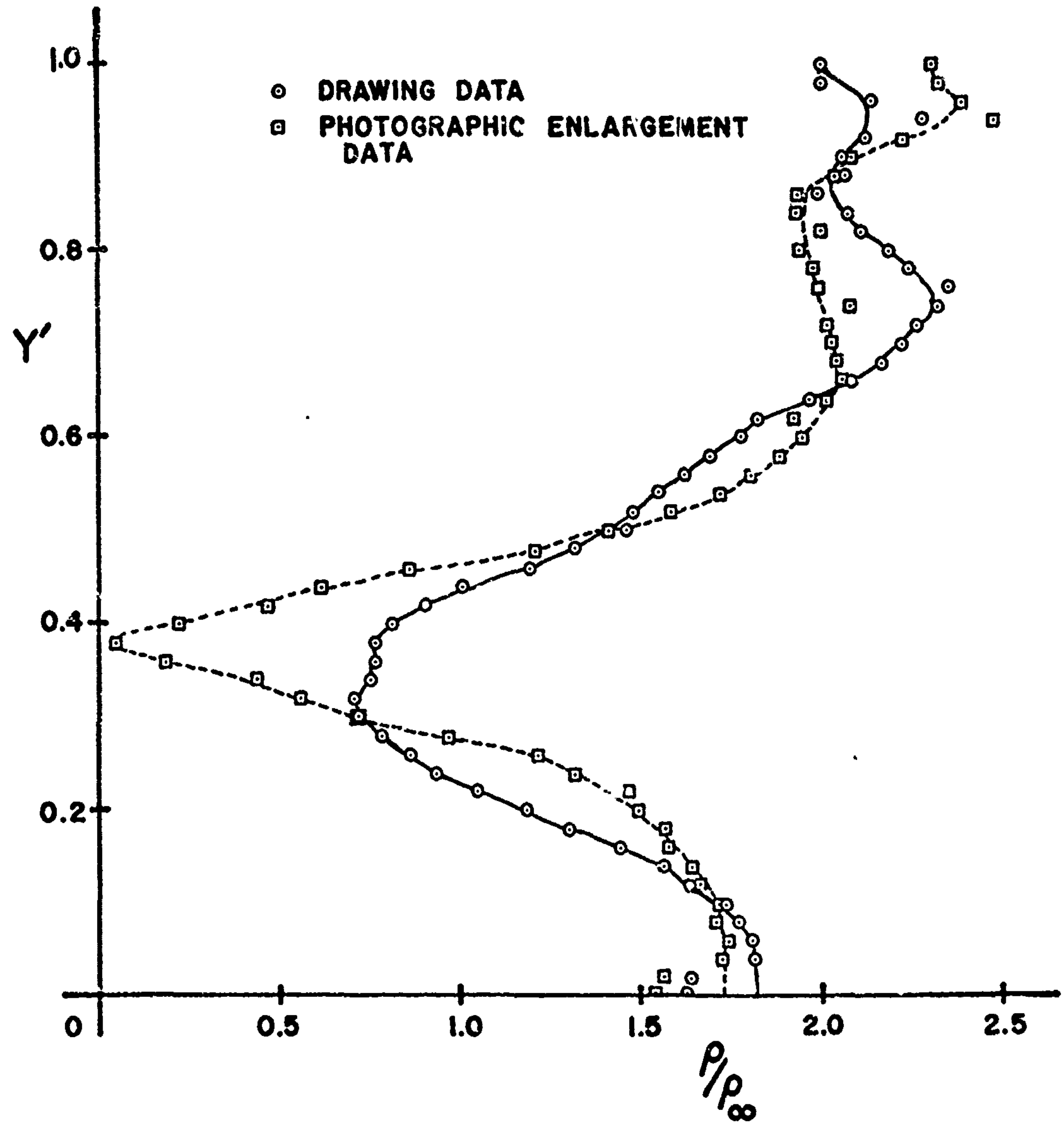

Figure 5?. Comparison of the Density Distributions Calculated by HOLOVIK for an Axisymmetric Case

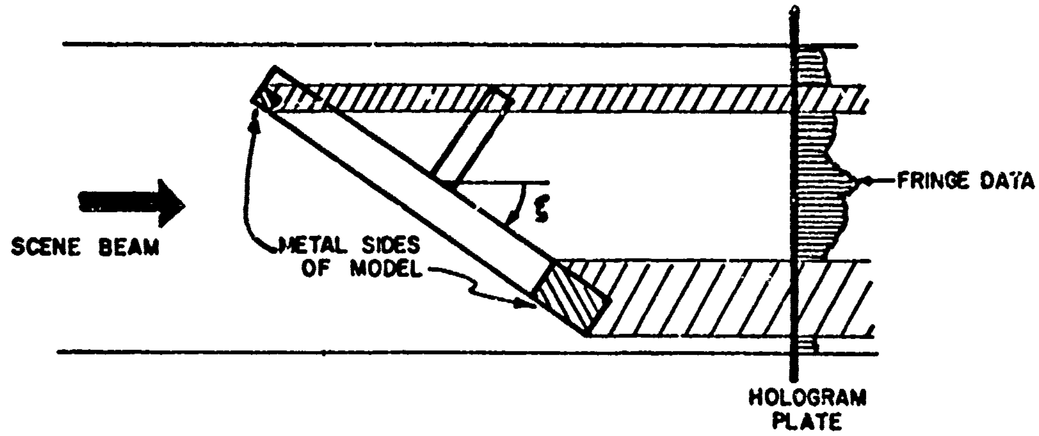

Figure 55. Schematic of the Model Center Section Rotated to Illustrate the Loss of Fringe Information Due to Model Shadows on the Hologram

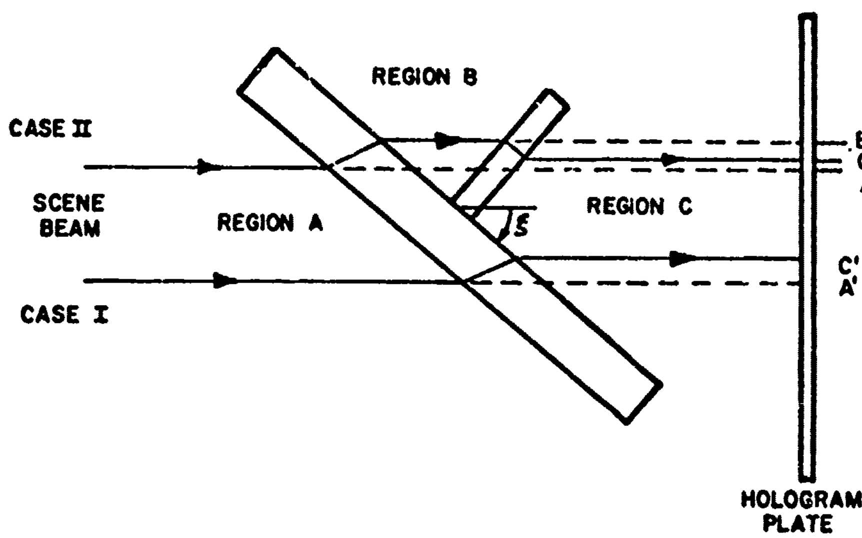

Figure 56. Schematic Illustrating the Problem of Different Fringe Information Being Superimposed on One Beam Caused by the Model Plastic

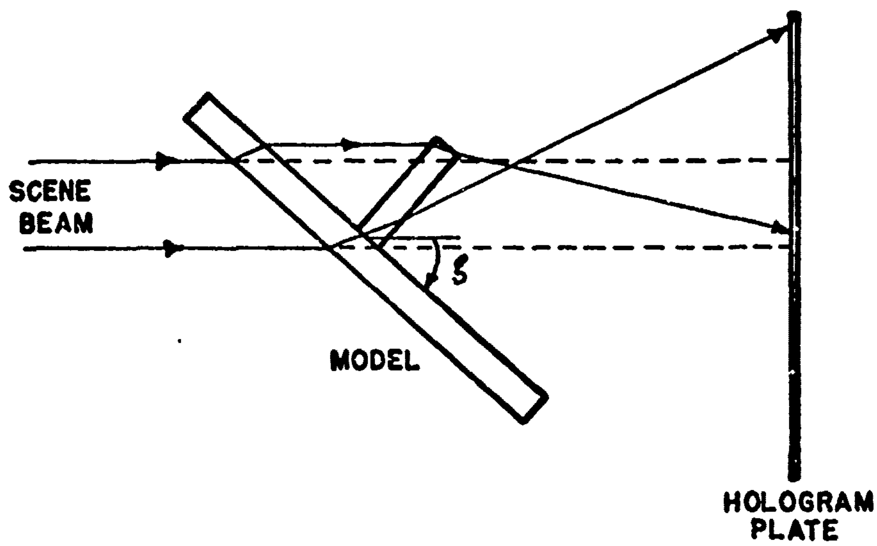

Figure 52. Schematic Illustrating the Scene Beam Refraction in the Fin Root and Tip Areas

Line No.	Distance Above Aligned Plane: Measured (inches)	Normalized ① wing height	Corrected Distance from Tables	Y' ③ = ② + .055	Fringe Location (inches) ④	Fringe Change f = ④ − ①	Fringe Number $g = \frac{f}{h}$	Amount of 1.1 Fringe Correction Required	Corrected Values Y'	Corrected Values g
1	.190	.075	.071	.126	.360	.170	1.641	1.1	.081	2.74
2	.330	.131	.124	.179	.460	.130	1.255	1.1	.134	2.36
3	.465	.185	.174	.231	.590	.125	1.208	1.1	.186	2.31
4	.570	.226	.215	.270	.570	.100	.965	1.1	.225	2.07
5	.660	.262	.249	.304	.765	.105	1.013	1.1	.259	2.11
6	.745	.296	.281	.336	.860	.115	1.110	1.1	.291	2.21
7	.825	.327	.311	.366	.950	.125	1.208	1.1	.321	2.31
8	.950	.377	.358	.413	1.090	.140	1.352	1.1	.368	2.45
9	1.060	.421	.400	.455	1.240	.180	1.737	1.1	.410	2.84
10	1.180	.468	.445	.500	1.350	.170	1.641	1.1	.455	2.74
11	1.245	.494	.469	.524	1.500	.255	2.172	1.1	.479	3.27
12	1.350	.536	.509	.564	1.620	.270	2.607	.5	.543	3.11
13	1.430	.567	.539	.594	1.750	.320	3.090	.1	.590	3.19
14	1.533	.609	.579	.634	1.850	.315	3.041	0.	.634	3.04
15	1.625	.649	.617	.672	1.940	.315	3.041	0.	.672	3.04
16	1.720	.683	.649	.704	2.030	.310	2.994	0.	.704	2.99
17	1.830	.726	.690	.745	2.120	.290	2.800	0.	.745	2.80
18	1.955	.776	.737	.792	2.220	.265	2.560	0.	.792	2.56
19	2.080	.825	.783	.838	2.290	.210	2.028	0.	.838	2.03
20	2.180	.865	.821	.876	2.340	.160	1.545	0.	.876	1.55
21	2.315	.919	.872	.927	2.400	.085	.820	0.	.927	.82
22	2.400	.952	.904	.959	2.500	.100	.965	0.	.959	.97
23	2.500	.992	.942	.997	2.580	.080	.772	0.	.997	.77
24	2.570	1.020	.969	1.024	2.670	.100	.965	0.	1.024	.97
25	2.680	1.063	1.009	1.064	2.790	.110	1.062	0.	1.064	1.06
26	2.780	1.103	1.048	1.103	2.885	.115	1.110	0.	1.103	1.11

Wing height = 2.52 inches   Wing length = 2.92 inches   Average fringe interval = .1036 inches

Table I. Tabulation of Fringe Shift Data Taken From the Drawing of Photo 4

Line No.	Distance Above Aligned Plane				Y' ④ = ③ + .055	Fringe Location (inches) ⑤	Fringe Change f = ⑤ - ②	Fringe Number g = $\frac{f}{b}$
	Measured (inches) ①	Corrected to Free Stream (inches) ②	Normalized ② / (wing height)	Corrected Distance from Tables ③				
1	.190*	.076	.032	.030	.085	.270	.194	1.867
2	.290	.176	.073	.069	.124	.390	.214	2.050
3	.410*	.296	.123	.117	.172	.450	.154	1.482
4	.525*	.411	.171	.162	.217	.560	.149	1.434
5	.615*	.501	.208	.198	.253	.650	.149	1.434
6	.710*	.596	.247	.235	.290	.725	.129	1.242
7	.800*	.686	.285	.271	.326	.830	.144	1.386
8	.910*	.796	.330	.314	.369	.980	.184	1.771
9	1.020*	.906	.376	.357	.412	1.140	.234	2.252
10	1.120*	1.006	.417	.396	.451	1.290	.284	2.738
11	1.230*	1.116	.463	.440	.495	1.420	.304	2.926
12	1.330*	1.216	.505	.480	.535	1.580	.364	3.503
13	1.370	1.370	.568	.540	.595	1.670	.300	2.887
14	1.460	1.460	.606	.576	.631	1.770	.310	2.984
15	1.560	1.560	.647	.615	.670	1.860	.300	2.887
16	1.660	1.660	.689	.655	.710	1.960	.300	2.887
17	1.760	1.760	.730	.694	.749	2.020	.260	2.502
18	1.880	1.880	.780	.741	.796	2.100	.220	2.117
19	2.000	2.000	.830	.788	.843	2.190	.190	1.829
20	2.110	2.110	.876	.832	.887	2.305	.195	1.877
21	2.220	2.220	.921	.875	.930	2.390	.170	1.704
22	2.330	2.330	.967	.919	.974	2.480	.150	1.444
23	2.445	2.445	1.015	.964	1.019	2.590	.145	1.396
24	2.570	2.570	1.066	1.013	1.068	2.680	.110	1.059
25	2.680	2.680	1.112	1.056	1.111	2.760	.080	.770
26	2.805	2.805	1.164	1.106	1.161	2.860	.055	.529

* Locations to be corrected to free stream conditions

Table II. Tabulation of Fringe Shift Data Taken From the Photographic Enlargement of Photo 4

APPENDIX A

REDUCTION OF AN INTERFEROGRAM TO OBTAIN FRINGE SHIFT DATA

The fringe shift reduction process was accomplished using two techniques. The first involved projecting the interferogram negative onto a sheet of white paper using a photo-enlarger. The light fringes offered the best contrast and were therefore traced out in Figures 30-34. In each drawing it was necessary to begin tracing the fringes above the fin and work towards the fin root since the transition across the fin tip determined the correct connection of the fringes across the fin leading edge shock. In order to determine the fringe change, one fringe line in the free stream region forward of the fin which appeared the straightest and paralleled the majority of other fringe lines was selected. A straight line, called the fringe reference line, was drawn over its centerline and extended to cross the y' axis. The remaining reference lines were then drawn parallel to the first and along the centerlines of the remaining free stream fringes. In reducing the drawings it was not realized until later that the free stream fringe patterns before and after the plate leading edge Prandtl-Meyer expansion differed considerably. This effect was taken into account later.

A ruler scaled to 0.01 inches was then placed along the y' axis and the distances of the fringes and reference lines above and below the aligned y' plane were then recorded in Table I for Photograph 4. The fin width and length were then measured and the average values were recorded. The average fringe interval was determined by measuring the distance between the first and last fringes used and dividing by the number of intervals. The fringe change was found by subtracting the fringe crossing

point. The fringe number was calculated by dividing the change by the average fringe interval. The reference line location was then normalized with respect to the measured fin height. Since the actual fin height was very close to one inch, the above number was considered to be the number of inches above or below the aligned plane. Thus the table computing the tunnel wall and grid refraction displacements in Appendix B could be entered to determine the actual reference line location with respect to the aligned plane of the drawing (see Figure 29). The locations were then converted to the y' axis system by adding the normalized location of the aligned plane. After realizing that not all the reference lines were referenced to the free stream density forward of the plate leading edge, the enlarged photographs (Figures 35-39) were checked against the drawings. It was found that the Prandtl-Meyer expansion caused a fringe number change of approximately 1.1. Consequently each reference line in the drawing was compared with the enlarged photograph and an appropriate percentage of the 1.1 fringe number was used as a correction (see Table I). The calculated fringe numbers had the correction fringe number added to them while the y' locations were corrected by

$$y'_{corr} = y'_{orig} - \frac{(1.1 \text{ Fringe no.}) \times (\text{Fringe Interval})}{(\text{Fin Height})} \qquad \text{(A-1)}$$

The second reduction technique was to use enlarged photographs made from the interferogram negatives to obtain the fringe change. The fringe lines were first traced over lightly with a pencil and then verified against the other photographs to ensure correct tracing. A datum fringe reference line was chosen as before and drawn. The remaining reference lines for the upper free stream fringe lines forward of the Prandtl-Meyer expansion were then drawn parallel to the datum. When it became impossible

to use fringe lines forward of the expansion, the reference lines were then drawn along the centerline of the fringes between the expansion and the fin. The same ruler was used to obtain the fringe crossing points, the reference crossing points, fin measurements, and the average fringe interval and they were recorded in Table 2. The reference line crossing points were then corrected to free stream conditions, using a 1.1 Fringe number correction for those referenced to the pattern between the expansion and fin leading edge. The fringe number and reference fin locations were calculated as before. This method was considered more accurate because the reference lines and fringe lines could easily be rechecked for accuracy and corrected in the event that a fringe line was traced incorrectly or a reference line was misaligned. The accuracy was directly proportional to the hologram resolution which was not true for th drawings since the reference lines are drawn parallel to hand-drawn fringe lines.

APPENDIX B

CALCULATION OF TUNNEL WALL AND GRID PLASTIC REFRACTION CORRECTION

In the interferogram photographs used to obtain the fringe change, every point off the alignment axis will be slightly distorted due to the plastic tunnel wall and grid. This effect is illustrated in Figure 19. From Snells Law of Refraction, the angles of incidence and refraction are related by

$$\sin\alpha = n \sin\beta \tag{B-1}$$

where n is the index of refraction between plastic and air. Then can be written

$$\beta = \sin^{-1}\left(\frac{\sin\alpha}{n}\right) \tag{B-2}$$

Since the tunnel wall and grid have the same index of refraction, they can be considered on. material with thickness t = ab in Figure 19. Then consider the height bd which can be written

$$bd = t \tan\alpha \tag{B-3}$$

The beam displacement, Δy, is then

$$\Delta Y = bd - bc = t \tan\alpha - t \tan\beta \tag{B-4}$$

but $\tan\alpha$ is

$$\tan\alpha = \frac{Y_{observed}}{L} \tag{B-5}$$

Combining Equation (B-2), (B-4), and (B-5) the beam displacement becomes

$$\Delta Y = t\left\{\frac{Y\ observed}{L} - \tan\left[\sin^{-1}\left(\frac{\sin\alpha}{n}\right)\right]\right\} \tag{B-6}$$

The true location of the observed point is then

$$Y_{true} = Y_{observed} - \Delta Y \tag{B-7}$$

A FORTRAN computer program was written to generate a table giving the true locations versus the observed locations. In the program the constants and variables from the above equations were defined as

$Y_{observed}$	=	Y
Y_{true}	=	YTRUE
ΔY	=	DY
α	=	ALFA
L	=	L
n		N

Since the computer cannot calculate Equations (B-2) and (B-6) as written, they were constructed by parts using such letters as AA, AB, etc. The program and tables are included in the next few pages.

```
C      ************************************************************
C      **                                                        **
C      **  THIS PROGRAM COMPUTES THE CORRECTION FOR THE          **
C      **  OFF AXIS TUNNEL WALL PARALLAX. THE FOLLOWING          **
C      **  INPUT PARAMETERS ARE REQUIRED:                        **
C      **  L = DISTANCE FROM HOLOGRAM PLANE TO THE MODEL         **
C      **      CENTER LINE                                       **
C      **  N = INDEX OF REFRACTION FOR TUNNEL WALL               **
C      **  T = THICKNESS OF TUNNEL AND GRID PLEXIGLAS            **
C      **  Y = OBSERVED DISTANCE OF THE POINT IN THE             **
C      **      PHOTOGRAPH FROM THE ALIGNED POINT                 **
C      **  YTRUE = TRUE DISTANCE FROM ALIGNED POINT TO           **
C      **          THE POINT ON THE MODEL PLANE                  **
C      **  YMAX = MAXIMUM DISTANCE OF INTEREST FROM THE          **
C      **         ALIGNED POINT                                  **
C      **                                                        **
C      ************************************************************
C
       REAL*4 L,N
C
C         INPUT PARAMETERS
C
       L=15.0
       N=1.5
       T=2.25
       YMAX=2.5
       PI=3.141593
C
C         OUTPUT FORMAT
C
       WRITE(6,100)L,N,T
   100 FORMAT('1',T25,'THE FOLLOWING TABLE IS TO ACCOUNT FOR'
      1' THE PARALLAX'/T25,'ERROR IN VIEWING THE MODEL '
      2'THROUGH GLASS WALLS AT'/T25,'ANY OTHER POINT THAN '
      3'AT THE ALIGNMENT POINT. INPUT'/T25,'PARAMETERS ARE:'
      4/T35,'(1) L = ',F6.3,' INCHES'/T35,'(2) N = ',F6.3,
      5' INCHES'/T35,'(3) T = ',F6.3,' INCHES')
       WRITE(6,110)
   110 FORMAT(' ',T24,'OBSERVED',T40,'TRUE',T54,'ERROR',T70,
      1'RAY'/T24,'DISTANCE',T38,'DISTANCE',T69,'ANGLE'/T24,
      2'(INCHES)',T38,'(INCHES)',T53,'(INCHES)',T67,
      3'(DEGREES)'/)
C
C         CALCULATIONS
C
       Y=0.0
    10 DO 15 I=1,2000
       AA=Y/L
       AB=ATAN(AA)
       ALFA=AB*180.0/PI
       AC=SIN(AB)/N
       BETA=ARSIN(AC)
       AD=TAN(BETA)
       DY=T*(AA-AD)
       YTRUE=Y-DY
C
       WRITE(6,200)Y,YTRUE,DY,ALFA
   200 FORMAT(' ',T24,F7.4,T38,F7.4,T53,F8.6,T67,F8.4)
       IF(MOD(I,10).EQ.0)WRITE(6,201)
   201 FORMAT(' ')
       IF(MOD(I,60).EQ.0)GO TO 11
       GO TO 12
    11 WRITE(6,202)
   202 FORMAT('1')
       WRITE(6,110)
    12 Y=.002*FLOAT(I)
       IF(Y.GE.YMAX)GO TO 20
    15 CONTINUE
    20 STOP
       END
```

THE FOLLOWING TABLE IS TO ACCOUNT FOR THE PARALLAX ERROR IN VIEWING THE MODEL THROUGH GLASS WALLS AT ANY OTHER POINT THAN AT THE ALIGNMENT POINT. INPUT PARAMETERS ARE:

(1) L = 15.000 INCHES
(2) N = 1.500 INCHES
(3) T = 2.250 INCHES

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.0	0.0	0.0	0.0
0.0020	0.0019	0.000100	0.0076
0.0040	0.0038	0.000200	0.0153
0.0060	0.0057	0.000300	0.0229
0.0080	0.0076	0.000400	0.0306
0.0100	0.0095	0.000500	0.0382
0.0120	0.0114	0.000600	0.0458
0.0140	0.0133	0.000700	0.0535
0.0160	0.0152	0.000800	0.0611
0.0180	0.0171	0.000900	0.0688
0.0200	0.0190	0.001000	0.0764
0.0220	0.0209	0.001100	0.0840
0.0240	0.0228	0.001200	0.0917
0.0260	0.0247	0.001300	0.0993
0.0280	0.0266	0.001400	0.1070
0.0300	0.0285	0.001500	0.1146
0.0320	0.0304	0.001600	0.1222
0.0340	0.0323	0.001700	0.1299
0.0360	0.0342	0.001800	0.1375
0.0380	0.0361	0.001900	0.1451
0.0400	0.0380	0.002000	0.1528
0.0420	0.0399	0.002100	0.1604
0.0440	0.0418	0.002200	0.1681
0.0460	0.0437	0.002300	0.1757
0.0480	0.0456	0.002400	0.1833
0.0500	0.0475	0.002500	0.1910
0.0520	0.0494	0.002600	0.1986
0.0540	0.0513	0.002700	0.2063
0.0560	0.0532	0.002800	0.2139
0.0580	0.0551	0.002900	0.2215
0.0600	0.0570	0.003000	0.2292
0.0620	0.0589	0.003100	0.2368
0.0640	0.0608	0.003200	0.2445
0.0660	0.0627	0.003300	0.2521
0.0680	0.0646	0.003400	0.2597
0.0700	0.0665	0.003500	0.2674
0.0720	0.0684	0.003600	0.2750
0.0740	0.0703	0.003700	0.2827
0.0760	0.0722	0.003800	0.2903
0.0780	0.0741	0.003900	0.2979
0.0800	0.0760	0.004000	0.3056
0.0820	0.0779	0.004100	0.3132
0.0840	0.0798	0.004200	0.3209
0.0860	0.0817	0.004300	0.3285
0.0880	0.0836	0.004400	0.3361
0.0900	0.0855	0.004500	0.3438
0.0920	0.0874	0.004600	0.3514
0.0940	0.0893	0.004700	0.3590
0.0960	0.0912	0.004800	0.3667
0.0980	0.0931	0.004900	0.3743
0.1000	0.0950	0.005000	0.3820
0.1020	0.0969	0.005100	0.3896
0.1040	0.0988	0.005200	0.3972
0.1060	0.1007	0.005300	0.4049
0.1080	0.1026	0.005400	0.4125
0.1100	0.1045	0.005500	0.4202
0.1120	0.1064	0.005600	0.4278
0.1140	0.1083	0.005700	0.4354
0.1160	0.1102	0.005800	0.4431
0.1180	0.1121	0.005900	0.4507

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.1200	0.1140	0.006000	0.4584
0.1220	0.1159	0.006100	0.4660
0.1240	0.1178	0.006200	0.4736
0.1260	0.1197	0.006300	0.4813
0.1280	0.1216	0.006400	0.4889
0.1300	0.1235	0.006500	0.4966
0.1320	0.1254	0.006600	0.5042
0.1340	0.1273	0.006700	0.5118
0.1360	0.1292	0.006800	0.5195
0.1380	0.1311	0.006900	0.5271
0.1400	0.1330	0.007000	0.5347
0.1420	0.1349	0.007100	0.5424
0.1440	0.1368	0.007200	0.5500
0.1460	0.1387	0.007300	0.5577
0.1480	0.1406	0.007400	0.5653
0.1500	0.1425	0.007500	0.5729
0.1520	0.1444	0.007600	0.5806
0.1540	0.1463	0.007700	0.5882
0.1560	0.1482	0.007800	0.5959
0.1580	0.1501	0.007901	0.6035
0.1600	0.1520	0.008001	0.6111
0.1620	0.1539	0.008101	0.6188
0.1640	0.1558	0.008201	0.6264
0.1660	0.1577	0.008301	0.6340
0.1680	0.1596	0.008401	0.6417
0.1700	0.1615	0.008501	0.6493
0.1720	0.1634	0.008601	0.6570
0.1740	0.1653	0.008701	0.6646
0.1760	0.1672	0.008801	0.6722
0.1780	0.1691	0.008901	0.6799
0.1800	0.1710	0.009001	0.6875
0.1820	0.1729	0.009101	0.6952
0.1840	0.1748	0.009201	0.7028
0.1860	0.1767	0.009301	0.7104
0.1880	0.1786	0.009401	0.7181
0.1900	0.1805	0.009501	0.7257
0.1920	0.1824	0.009601	0.7333
0.1940	0.1843	0.009701	0.7410
0.1960	0.1862	0.009801	0.7486
0.1980	0.1881	0.009901	0.7563
0.2000	0.1900	0.010001	0.7639
0.2020	0.1919	0.010101	0.7715
0.2040	0.1938	0.010201	0.7792
0.2060	0.1957	0.010301	0.7868
0.2080	0.1976	0.010401	0.7944
0.2100	0.1995	0.010501	0.8021
0.2120	0.2014	0.010601	0.8097
0.2140	0.2033	0.010701	0.8174
0.2160	0.2052	0.010801	0.8250
0.2180	0.2071	0.010901	0.8326
0.2200	0.2090	0.011001	0.8403
0.2220	0.2109	0.011101	0.8479
0.2240	0.2128	0.011201	0.8556
0.2260	0.2147	0.011301	0.8632
0.2280	0.2166	0.011401	0.8708
0.2300	0.2185	0.011502	0.8785
0.2320	0.2204	0.011602	0.8861
0.2340	0.2223	0.011702	0.8937
0.2360	0.2242	0.011802	0.9014
0.2380	0.2261	0.011902	0.9090

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.2400	0.2280	0.012002	0.9167
0.2420	0.2299	0.012102	0.9243
0.2440	0.2318	0.012202	0.9319
0.2460	0.2337	0.012302	0.9396
0.2480	0.2356	0.012402	0.9472
0.2500	0.2375	0.012502	0.9548
0.2520	0.2394	0.012602	0.9625
0.2540	0.2413	0.012702	0.9701
0.2560	0.2432	0.012802	0.9778
0.2580	0.2451	0.012902	0.9854
0.2600	0.2470	0.013002	0.9930
0.2620	0.2489	0.013102	1.0007
0.2640	0.2508	0.013202	1.0083
0.2660	0.2527	0.013302	1.0159
0.2680	0.2546	0.013402	1.0236
0.2700	0.2565	0.013502	1.0312
0.2720	0.2584	0.013602	1.0388
0.2740	0.2603	0.013703	1.0465
0.2760	0.2622	0.013803	1.0541
0.2780	0.2641	0.013903	1.0618
0.2800	0.2660	0.014003	1.0694
0.2820	0.2679	0.014103	1.0770
0.2840	0.2698	0.014203	1.0847
0.2860	0.2717	0.014303	1.0923
0.2880	0.2736	0.014403	1.0999
0.2900	0.2755	0.014503	1.1076
0.2920	0.2774	0.014603	1.1152
0.2940	0.2793	0.014703	1.1229
0.2960	0.2812	0.014803	1.1305
0.2980	0.2831	0.014903	1.1381
0.3000	0.2850	0.015003	1.1458
0.3020	0.2869	0.015103	1.1534
0.3040	0.2888	0.015203	1.1610
0.3060	0.2907	0.015304	1.1687
0.3080	0.2926	0.015404	1.1763
0.3100	0.2945	0.015504	1.1839
0.3120	0.2964	0.015604	1.1916
0.3140	0.2983	0.015704	1.1992
0.3160	0.3002	0.015804	1.2069
0.3180	0.3021	0.015904	1.2145
0.3200	0.3040	0.016004	1.2221
0.3220	0.3059	0.016104	1.2298
0.3240	0.3078	0.016204	1.2374
0.3260	0.3097	0.016304	1.2450
0.3280	0.3116	0.016404	1.2527
0.3300	0.3135	0.016504	1.2603
0.3320	0.3154	0.016605	1.2679
0.3340	0.3173	0.016705	1.2756
0.3360	0.3192	0.016805	1.2832
0.3380	0.3211	0.016905	1.2908
0.3400	0.3230	0.017005	1.2985
0.3420	0.3249	0.017105	1.3061
0.3440	0.3268	0.017205	1.3138
0.3460	0.3287	0.017305	1.3214
0.3480	0.3306	0.017405	1.3290
0.3500	0.3325	0.017505	1.3367
0.3520	0.3344	0.017605	1.3443
0.3540	0.3363	0.017705	1.3519
0.3560	0.3382	0.017806	1.3596
0.3580	0.3401	0.017906	1.3672

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.3600	0.3420	0.018006	1.3748
0.3620	0.3439	0.018106	1.3825
0.3640	0.3458	0.018206	1.3901
0.3660	0.3477	0.018306	1.3977
0.3680	0.3496	0.018406	1.4054
0.3700	0.3515	0.018506	1.4130
0.3720	0.3534	0.018606	1.4206
0.3740	0.3553	0.018706	1.4283
0.3760	0.3572	0.018807	1.4359
0.3780	0.3591	0.018907	1.4435
0.3800	0.3610	0.019007	1.4512
0.3820	0.3629	0.019107	1.4588
0.3840	0.3648	0.019207	1.4665
0.3860	0.3667	0.019307	1.4741
0.3880	0.3686	0.019407	1.4817
0.3900	0.3705	0.019507	1.4894
0.3920	0.3724	0.019607	1.4970
0.3940	0.3743	0.019708	1.5046
0.3960	0.3762	0.019808	1.5123
0.3980	0.3781	0.019908	1.5199
0.4000	0.3800	0.020008	1.5275
0.4020	0.3819	0.020108	1.5352
0.4040	0.3838	0.020208	1.5428
0.4060	0.3857	0.020308	1.5504
0.4080	0.3876	0.020408	1.5581
0.4100	0.3895	0.020509	1.5657
0.4120	0.3914	0.020609	1.5733
0.4140	0.3933	0.020709	1.5810
0.4160	0.3952	0.020809	1.5886
0.4180	0.3971	0.020909	1.5962
0.4200	0.3990	0.021009	1.6039
0.4220	0.4009	0.021109	1.6115
0.4240	0.4028	0.021209	1.6191
0.4260	0.4047	0.021310	1.6268
0.4280	0.4066	0.021410	1.6344
0.4300	0.4085	0.021510	1.6420
0.4320	0.4104	0.021610	1.6497
0.4340	0.4123	0.021710	1.6573
0.4360	0.4142	0.021810	1.6649
0.4380	0.4161	0.021910	1.6726
0.4400	0.4180	0.022011	1.6802
0.4420	0.4199	0.022111	1.6878
0.4440	0.4218	0.022211	1.6955
0.4460	0.4237	0.022311	1.7031
0.4480	0.4256	0.022411	1.7107
0.4500	0.4275	0.022511	1.7184
0.4520	0.4294	0.022611	1.7260
0.4540	0.4313	0.022712	1.7336
0.4560	0.4332	0.022812	1.7413
0.4580	0.4351	0.022912	1.7489
0.4600	0.4370	0.023012	1.7565
0.4620	0.4389	0.023112	1.7642
0.4640	0.4408	0.023212	1.7718
0.4660	0.4427	0.023312	1.7794
0.4680	0.4446	0.023413	1.7870
0.4700	0.4465	0.023513	1.7947
0.4720	0.4484	0.023613	1.8023
0.4740	0.4503	0.023713	1.8099
0.4760	0.4522	0.023813	1.8176
0.4780	0.4541	0.023913	1.8252

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.4800	0.4560	0.024014	1.8328
0.4820	0.4579	0.024114	1.8405
0.4840	0.4598	0.024214	1.8481
0.4860	0.4617	0.024314	1.8557
0.4880	0.4636	0.024414	1.8634
0.4900	0.4655	0.024515	1.8710
0.4920	0.4674	0.024615	1.8786
0.4940	0.4693	0.024715	1.8863
0.4960	0.4712	0.024815	1.8939
0.4980	0.4731	0.024915	1.9015
0.5000	0.4750	0.025015	1.9092
0.5020	0.4769	0.025116	1.9168
0.5040	0.4788	0.025216	1.9244
0.5060	0.4807	0.025316	1.9320
0.5080	0.4826	0.025416	1.9397
0.5100	0.4845	0.025516	1.9473
0.5120	0.4864	0.025617	1.9549
0.5140	0.4883	0.025717	1.9626
0.5160	0.4902	0.025817	1.9702
0.5180	0.4921	0.025917	1.9778
0.5200	0.4940	0.026017	1.9855
0.5220	0.4959	0.026118	1.9931
0.5240	0.4978	0.026218	2.0007
0.5260	0.4997	0.026318	2.0083
0.5280	0.5016	0.026418	2.0160
0.5300	0.5035	0.026518	2.0236
0.5320	0.5054	0.026619	2.0312
0.5340	0.5073	0.026719	2.0389
0.5360	0.5092	0.026819	2.0465
0.5380	0.5111	0.026919	2.0541
0.5400	0.5130	0.027019	2.0618
0.5420	0.5149	0.027120	2.0694
0.5440	0.5168	0.027220	2.0770
0.5460	0.5187	0.027320	2.0846
0.5480	0.5206	0.027420	2.0923
0.5500	0.5225	0.027521	2.0999
0.5520	0.5244	0.027621	2.1075
0.5540	0.5263	0.027721	2.1152
0.5560	0.5282	0.027821	2.1228
0.5580	0.5301	0.027921	2.1304
0.5600	0.5320	0.028022	2.1380
0.5620	0.5339	0.028122	2.1457
0.5640	0.5358	0.028222	2.1533
0.5660	0.5377	0.028322	2.1609
0.5680	0.5396	0.028423	2.1686
0.5700	0.5415	0.028523	2.1762
0.5720	0.5434	0.028623	2.1838
0.5740	0.5453	0.028723	2.1914
0.5760	0.5472	0.028824	2.1991
0.5780	0.5491	0.028924	2.2067
0.5800	0.5510	0.029024	2.2143
0.5820	0.5529	0.029124	2.2220
0.5840	0.5548	0.029225	2.2296
0.5860	0.5567	0.029325	2.2372
0.5880	0.5586	0.029425	2.2448
0.5900	0.5605	0.029525	2.2525
0.5920	0.5624	0.029625	2.2601
0.5940	0.5643	0.029726	2.2677
0.5960	0.5662	0.029826	2.2754
0.5980	0.5681	0.029926	2.2830

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.6000	0.5700	0.030027	2.2906
0.6020	0.5719	0.030127	2.2982
0.6040	0.5738	0.030227	2.3059
0.6060	0.5757	0.030327	2.3135
0.6080	0.5776	0.030428	2.3211
0.6100	0.5795	0.030528	2.3287
0.6120	0.5814	0.030628	2.3364
0.6140	0.5833	0.030729	2.3440
0.6160	0.5852	0.030829	2.3516
0.6180	0.5871	0.030929	2.3593
0.6200	0.5890	0.031029	2.3669
0.6220	0.5909	0.031130	2.3745
0.6240	0.5928	0.031230	2.3821
0.6260	0.5947	0.031330	2.3898
0.6280	0.5966	0.031431	2.3974
0.6300	0.5985	0.031531	2.4050
0.6320	0.6004	0.031631	2.4126
0.6340	0.6023	0.031731	2.4203
0.6360	0.6042	0.031832	2.4279
0.6380	0.6061	0.031932	2.4355
0.6400	0.6080	0.032032	2.4431
0.6420	0.6099	0.032133	2.4508
0.6440	0.6118	0.032233	2.4584
0.6460	0.6137	0.032333	2.4660
0.6480	0.6156	0.032434	2.4736
0.6500	0.6175	0.032534	2.4813
0.6520	0.6194	0.032634	2.4889
0.6540	0.6213	0.032735	2.4965
0.6560	0.6232	0.032835	2.5041
0.6580	0.6251	0.032935	2.5118
0.6600	0.6270	0.033035	2.5194
0.6620	0.6289	0.033136	2.5270
0.6640	0.6308	0.033236	2.5346
0.6660	0.6327	0.033336	2.5423
0.6680	0.6346	0.033437	2.5499
0.6700	0.6365	0.033537	2.5575
0.6720	0.6384	0.033637	2.5651
0.6740	0.6403	0.033738	2.5728
0.6760	0.6422	0.033838	2.5804
0.6780	0.6441	0.033938	2.5880
0.6800	0.6460	0.034039	2.5956
0.6820	0.6479	0.034139	2.6033
0.6840	0.6498	0.034239	2.6109
0.6860	0.6517	0.034340	2.6185
0.6880	0.6536	0.034440	2.6261
0.6900	0.6555	0.034541	2.6337
0.6920	0.6574	0.034641	2.6414
0.6940	0.6593	0.034741	2.6490
0.6960	0.6612	0.034842	2.6566
0.6980	0.6631	0.034942	2.6642
0.7000	0.6650	0.035042	2.6719
0.7020	0.6669	0.035143	2.6795
0.7040	0.6688	0.035243	2.6871
0.7060	0.6707	0.035343	2.6947
0.7080	0.6726	0.035444	2.7024
0.7100	0.6745	0.035544	2.7100
0.7120	0.6764	0.035645	2.7176
0.7140	0.6783	0.035745	2.7252
0.7160	0.6802	0.035845	2.7328
0.7180	0.6821	0.035946	2.7405

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.7200	0.6840	0.036046	2.7481
0.7220	0.6859	0.036146	2.7557
0.7240	0.6878	0.036247	2.7633
0.7260	0.6897	0.036347	2.7710
0.7280	0.6916	0.036448	2.7786
0.7300	0.6935	0.036548	2.7862
0.7320	0.6954	0.036648	2.7938
0.7340	0.6973	0.036749	2.8014
0.7360	0.6992	0.036849	2.8091
0.7380	0.7011	0.036950	2.8167
0.7400	0.7029	0.037050	2.8243
0.7420	0.7048	0.037150	2.8319
0.7440	0.7067	0.037251	2.8395
0.7460	0.7086	0.037351	2.8472
0.7480	0.7105	0.037452	2.8548
0.7500	0.7124	0.037552	2.8624
0.7520	0.7143	0.037652	2.8700
0.7540	0.7162	0.037753	2.8776
0.7560	0.7181	0.037853	2.8853
0.7580	0.7200	0.037954	2.8929
0.7600	0.7219	0.038054	2.9005
0.7620	0.7238	0.038155	2.9081
0.7640	0.7257	0.038255	2.9157
0.7660	0.7276	0.038355	2.9234
0.7680	0.7295	0.038456	2.9310
0.7700	0.7314	0.038556	2.9386
0.7720	0.7333	0.038657	2.9462
0.7740	0.7352	0.038757	2.9538
0.7760	0.7371	0.038858	2.9615
0.7780	0.7390	0.038958	2.9691
0.7800	0.7409	0.039059	2.9767
0.7820	0.7428	0.039159	2.9843
0.7840	0.7447	0.039259	2.9919
0.7860	0.7466	0.039360	2.9996
0.7880	0.7485	0.039460	3.0072
0.7900	0.7504	0.039561	3.0148
0.7920	0.7523	0.039661	3.0224
0.7940	0.7542	0.039762	3.0300
0.7960	0.7561	0.039862	3.0376
0.7980	0.7580	0.039963	3.0453
0.8000	0.7599	0.040063	3.0529
0.8020	0.7618	0.040164	3.0605
0.8040	0.7637	0.040264	3.0681
0.8060	0.7656	0.040365	3.0757
0.8080	0.7675	0.040465	3.0834
0.8100	0.7694	0.040566	3.0910
0.8120	0.7713	0.040666	3.0986
0.8140	0.7732	0.040767	3.1062
0.8160	0.7751	0.040867	3.1138
0.8180	0.7770	0.040968	3.1214
0.8200	0.7789	0.041068	3.1291
0.8220	0.7808	0.041169	3.1367
0.8240	0.7827	0.041269	3.1443
0.8260	0.7846	0.041369	3.1519
0.8280	0.7865	0.041470	3.1595
0.8300	0.7884	0.041570	3.1671
0.8320	0.7903	0.041671	3.1748
0.8340	0.7922	0.041772	3.1824
0.8360	0.7941	0.041872	3.1900
0.8380	0.7960	0.041973	3.1976

CBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.8400	0.7979	0.042073	3.2052
0.8420	0.7998	0.042174	3.2128
0.8440	0.8017	0.042274	3.2204
0.8460	0.8036	0.042375	3.2281
0.8480	0.8055	0.042475	3.2357
0.8500	0.8074	0.042576	3.2433
0.8520	0.8093	0.042676	3.2509
0.8540	0.8112	0.042777	3.2585
0.8560	0.8131	0.042877	3.2661
0.8580	0.8150	0.042978	3.2738
0.8600	0.8169	0.043078	3.2814
0.8620	0.8188	0.043179	3.2890
0.8640	0.8207	0.043280	3.2966
0.8660	0.8226	0.043380	3.3042
0.8680	0.8245	0.043481	3.3118
0.8700	0.8264	0.043581	3.3194
0.8720	0.8283	0.043682	3.3270
0.8740	0.8302	0.043782	3.3347
0.8760	0.8321	0.043883	3.3423
0.8780	0.8340	0.043983	3.3499
0.8800	0.8359	0.044084	3.3575
0.8820	0.8378	0.044185	3.3651
0.8840	0.8397	0.044285	3.3727
0.8860	0.8416	0.044386	3.3803
0.8880	0.8435	0.044486	3.3880
0.8900	0.8454	0.044587	3.3956
0.8920	0.8473	0.044688	3.4032
0.8940	0.8492	0.044788	3.4108
0.8960	0.8511	0.044889	3.4184
0.8980	0.8530	0.044989	3.4260
0.9000	0.8549	0.045090	3.4336
0.9020	0.8568	0.045190	3.4412
0.9040	0.8587	0.045291	3.4489
0.9060	0.8606	0.045392	3.4565
0.9080	0.8625	0.045492	3.4641
0.9100	0.8644	0.045593	3.4717
0.9120	0.8663	0.045693	3.4793
0.9140	0.8682	0.045794	3.4869
0.9160	0.8701	0.045895	3.4945
0.9180	0.8720	0.045995	3.5021
0.9200	0.8739	0.046096	3.5097
0.9220	0.8758	0.046197	3.5174
0.9240	0.8777	0.046297	3.5250
0.9260	0.8796	0.046398	3.5326
0.9280	0.8815	0.046499	3.5402
0.9300	0.8834	0.046599	3.5478
0.9320	0.8853	0.046700	3.5554
0.9340	0.8872	0.046800	3.5630
0.9360	0.8891	0.046901	3.5706
0.9380	0.8910	0.047002	3.5782
0.9400	0.8929	0.047102	3.5858
0.9420	0.8948	0.047203	3.5935
0.9440	0.8967	0.047304	3.6011
0.9460	0.8986	0.047404	3.6087
0.9480	0.9005	0.047505	3.6163
0.9500	0.9024	0.047606	3.6239
0.9520	0.9043	0.047706	3.6315
0.9540	0.9062	0.047807	3.6391
0.9560	0.9081	0.047908	3.6467
0.9580	0.9100	0.048009	3.6543

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
0.9600	0.9119	0.048109	3.6619
0.9620	0.9138	0.048210	3.6695
0.9640	0.9157	0.048310	3.6771
0.9660	0.9176	0.048411	3.6848
0.9680	0.9195	0.048512	3.6924
0.9700	0.9214	0.048613	3.7000
0.9720	0.9233	0.048713	3.7076
0.9740	0.9252	0.048814	3.7152
0.9760	0.9271	0.048915	3.7228
0.9780	0.9290	0.049015	3.7304
0.9800	0.9309	0.049116	3.7380
0.9820	0.9328	0.049217	3.7456
0.9840	0.9347	0.049318	3.7532
0.9860	0.9366	0.049418	3.7608
0.9880	0.9385	0.049519	3.7684
0.9900	0.9404	0.049620	3.7760
0.9920	0.9423	0.049720	3.7836
0.9940	0.9442	0.049821	3.7913
0.9960	0.9461	0.049922	3.7989
0.9980	0.9480	0.050023	3.8065
1.0000	0.9499	0.050123	3.8141
1.0020	0.9518	0.050224	3.8217
1.0040	0.9537	0.050325	3.8293
1.0060	0.9556	0.050426	3.8369
1.0080	0.9575	0.050526	3.8445
1.0100	0.9594	0.050627	3.8521
1.0120	0.9613	0.050728	3.8597
1.0140	0.9632	0.050829	3.8673
1.0160	0.9651	0.050929	3.8749
1.0180	0.9670	0.051030	3.8825
1.0200	0.9689	0.051131	3.8901
1.0220	0.9708	0.051232	3.8977
1.0240	0.9727	0.051332	3.9053
1.0260	0.9746	0.051433	3.9129
1.0280	0.9765	0.051534	3.9205
1.0300	0.9784	0.051635	3.9281
1.0320	0.9803	0.051735	3.9357
1.0340	0.9822	0.051836	3.9433
1.0360	0.9841	0.051937	3.9509
1.0380	0.9860	0.052038	3.9586
1.0400	0.9879	0.052139	3.9662
1.0420	0.9898	0.052240	3.9738
1.0440	0.9917	0.052340	3.9814
1.0460	0.9936	0.052441	3.9890
1.0480	0.9955	0.052542	3.9966
1.0500	0.9974	0.052643	4.0042
1.0520	0.9993	0.052743	4.0118
1.0540	1.0012	0.052844	4.0194
1.0560	1.0031	0.052945	4.0270
1.0580	1.0050	0.053046	4.0346
1.0600	1.0069	0.053147	4.0422
1.0620	1.0088	0.053248	4.0498
1.0640	1.0107	0.053348	4.0574
1.0660	1.0125	0.053449	4.0650
1.0680	1.0144	0.053550	4.0726
1.0700	1.0163	0.053651	4.0802
1.0720	1.0182	0.053752	4.0878
1.0740	1.0201	0.053853	4.0954
1.0760	1.0220	0.053953	4.1030
1.0780	1.0239	0.054054	4.1106

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.0800	1.0258	0.054155	4.1182
1.0820	1.0277	0.054256	4.1258
1.0840	1.0296	0.054357	4.1334
1.0860	1.0315	0.054458	4.1410
1.0880	1.0334	0.054559	4.1486
1.0900	1.0353	0.054660	4.1562
1.0920	1.0372	0.054760	4.1638
1.0940	1.0391	0.054861	4.1714
1.0960	1.0410	0.054962	4.1790
1.0980	1.0429	0.055063	4.1866
1.1000	1.0448	0.055164	4.1942
1.1020	1.0467	0.055265	4.2018
1.1040	1.0486	0.055366	4.2094
1.1060	1.0505	0.055467	4.2170
1.1080	1.0524	0.055568	4.2246
1.1100	1.0543	0.055668	4.2322
1.1120	1.0562	0.055769	4.2398
1.1140	1.0581	0.055870	4.2474
1.1160	1.0600	0.055971	4.2550
1.1180	1.0619	0.056072	4.2626
1.1200	1.0638	0.056173	4.2702
1.1220	1.0657	0.056274	4.2778
1.1240	1.0676	0.056375	4.2854
1.1260	1.0695	0.056476	4.2929
1.1280	1.0714	0.056577	4.3005
1.1300	1.0733	0.056678	4.3081
1.1320	1.0752	0.056779	4.3157
1.1340	1.0771	0.056880	4.3233
1.1360	1.0790	0.056981	4.3309
1.1380	1.0809	0.057082	4.3385
1.1400	1.0828	0.057183	4.3461
1.1420	1.0847	0.057284	4.3537
1.1440	1.0866	0.057385	4.3613
1.1460	1.0885	0.057486	4.3689
1.1480	1.0904	0.057586	4.3765
1.1500	1.0923	0.057687	4.3841
1.1520	1.0942	0.057788	4.3917
1.1540	1.0961	0.057889	4.3993
1.1560	1.0980	0.057990	4.4069
1.1580	1.0999	0.058091	4.4145
1.1600	1.1018	0.058192	4.4221
1.1620	1.1037	0.058293	4.4297
1.1640	1.1056	0.058394	4.4373
1.1660	1.1075	0.058495	4.4448
1.1680	1.1094	0.058596	4.4524
1.1700	1.1113	0.058697	4.4600
1.1720	1.1132	0.058798	4.4676
1.1740	1.1151	0.058899	4.4752
1.1760	1.1170	0.059000	4.4828
1.1780	1.1189	0.059101	4.4904
1.1800	1.1208	0.059202	4.4980
1.1820	1.1227	0.059303	4.5056
1.1840	1.1246	0.059404	4.5132
1.1860	1.1265	0.059506	4.5208
1.1880	1.1284	0.059607	4.5284
1.1900	1.1303	0.059708	4.5360
1.1920	1.1322	0.059809	4.5436
1.1940	1.1341	0.059910	4.5511
1.1960	1.1360	0.060011	4.5587
1.1980	1.1379	0.060112	4.5663

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.2000	1.1398	0.060213	4.5739
1.2020	1.1417	0.060314	4.5815
1.2040	1.1436	0.060415	4.5891
1.2060	1.1455	0.060516	4.5967
1.2080	1.1474	0.060617	4.6043
1.2100	1.1493	0.060718	4.6119
1.2120	1.1512	0.060819	4.6195
1.2140	1.1531	0.060920	4.6270
1.2160	1.1550	0.061021	4.6346
1.2180	1.1569	0.061123	4.6422
1.2200	1.1588	0.061224	4.6498
1.2220	1.1607	0.061325	4.6574
1.2240	1.1626	0.061426	4.6650
1.2260	1.1645	0.061527	4.6726
1.2280	1.1664	0.061628	4.6802
1.2300	1.1683	0.061729	4.6878
1.2320	1.1702	0.061830	4.6954
1.2340	1.1721	0.061931	4.7029
1.2360	1.1740	0.062032	4.7105
1.2380	1.1759	0.062134	4.7181
1.2400	1.1778	0.062235	4.7257
1.2420	1.1797	0.062336	4.7333
1.2440	1.1816	0.062437	4.7409
1.2460	1.1835	0.062538	4.7485
1.2480	1.1854	0.062639	4.7560
1.2500	1.1873	0.062740	4.7636
1.2520	1.1892	0.062842	4.7712
1.2540	1.1911	0.062943	4.7788
1.2560	1.1930	0.063044	4.7864
1.2580	1.1949	0.063145	4.7940
1.2600	1.1968	0.063246	4.8016
1.2620	1.1987	0.063348	4.8092
1.2640	1.2006	0.063448	4.8167
1.2660	1.2024	0.063550	4.8243
1.2680	1.2043	0.063651	4.8319
1.2700	1.2062	0.063752	4.8395
1.2720	1.2081	0.063854	4.8471
1.2740	1.2100	0.063955	4.8547
1.2760	1.2119	0.064056	4.8622
1.2780	1.2138	0.064157	4.8698
1.2800	1.2157	0.064258	4.8774
1.2820	1.2176	0.064360	4.8850
1.2840	1.2195	0.064461	4.8926
1.2860	1.2214	0.064562	4.9002
1.2880	1.2233	0.064663	4.9078
1.2900	1.2252	0.064764	4.9153
1.2920	1.2271	0.064865	4.9229
1.2940	1.2290	0.064967	4.9305
1.2960	1.2309	0.065068	4.9381
1.2980	1.2328	0.065169	4.9457
1.3000	1.2347	0.065270	4.9533
1.3020	1.2366	0.065372	4.9608
1.3040	1.2385	0.065473	4.9684
1.3060	1.2404	0.065574	4.9760
1.3080	1.2423	0.065675	4.9836
1.3100	1.2442	0.065777	4.9912
1.3120	1.2461	0.065878	4.9987
1.3140	1.2480	0.065979	5.0063
1.3160	1.2499	0.066081	5.0139
1.3180	1.2518	0.066182	5.0215

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.3200	1.2537	0.066283	5.0291
1.3220	1.2556	0.066384	5.0366
1.3240	1.2575	0.066486	5.0442
1.3260	1.2594	0.066587	5.0518
1.3280	1.2613	0.066688	5.0594
1.3300	1.2632	0.066789	5.0670
1.3320	1.2651	0.066891	5.0745
1.3340	1.2670	0.066992	5.0821
1.3360	1.2689	0.067093	5.0897
1.3380	1.2708	0.067195	5.0973
1.3400	1.2727	0.067296	5.1049
1.3420	1.2746	0.067398	5.1124
1.3440	1.2765	0.067499	5.1200
1.3460	1.2784	0.067600	5.1276
1.3480	1.2803	0.067701	5.1352
1.3500	1.2822	0.067803	5.1428
1.3520	1.2841	0.067904	5.1503
1.3540	1.2860	0.068005	5.1579
1.3560	1.2879	0.068107	5.1655
1.3580	1.2898	0.068208	5.1731
1.3600	1.2917	0.068309	5.1806
1.3620	1.2936	0.068411	5.1882
1.3640	1.2955	0.068512	5.1958
1.3660	1.2974	0.068614	5.2034
1.3680	1.2993	0.068715	5.2110
1.3700	1.3012	0.068816	5.2185
1.3720	1.3031	0.068918	5.2261
1.3740	1.3050	0.069019	5.2337
1.3760	1.3069	0.069121	5.2413
1.3780	1.3088	0.069222	5.2488
1.3800	1.3107	0.069323	5.2564
1.3820	1.3126	0.069425	5.2640
1.3840	1.3145	0.069526	5.2716
1.3860	1.3164	0.069628	5.2791
1.3880	1.3183	0.069729	5.2867
1.3900	1.3202	0.069830	5.2943
1.3920	1.3221	0.069932	5.3019
1.3940	1.3240	0.070033	5.3094
1.3960	1.3259	0.070135	5.3170
1.3980	1.3278	0.070236	5.3246
1.4000	1.3297	0.070338	5.3322
1.4020	1.3316	0.070439	5.3397
1.4040	1.3335	0.070540	5.3473
1.4060	1.3354	0.070642	5.3549
1.4080	1.3373	0.070743	5.3624
1.4100	1.3392	0.070845	5.3700
1.4120	1.3411	0.070946	5.3776
1.4140	1.3430	0.071048	5.3852
1.4160	1.3448	0.071149	5.3927
1.4180	1.3467	0.071251	5.4003
1.4200	1.3486	0.071352	5.4079
1.4220	1.3505	0.071454	5.4154
1.4240	1.3524	0.071555	5.4230
1.4260	1.3543	0.071657	5.4306
1.4280	1.3562	0.071758	5.4382
1.4300	1.3581	0.071860	5.4457
1.4320	1.3600	0.071961	5.4533
1.4340	1.3619	0.072063	5.4609
1.4360	1.3638	0.072164	5.4684
1.4380	1.3657	0.072266	5.4760

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.4400	1.3676	0.072367	5.4836
1.4420	1.3695	0.072469	5.4912
1.4440	1.3714	0.072571	5.4987
1.4460	1.3733	0.072672	5.5063
1.4480	1.3752	0.072774	5.5139
1.4500	1.3771	0.072875	5.5214
1.4520	1.3790	0.072977	5.5290
1.4540	1.3809	0.073078	5.5366
1.4560	1.3828	0.073180	5.5441
1.4580	1.3847	0.073281	5.5517
1.4600	1.3866	0.073383	5.5593
1.4620	1.3885	0.073484	5.5668
1.4640	1.3904	0.073586	5.5744
1.4660	1.3923	0.073687	5.5820
1.4680	1.3942	0.073789	5.5895
1.4700	1.3961	0.073891	5.5971
1.4720	1.3980	0.073992	5.6047
1.4740	1.3999	0.074094	5.6122
1.4760	1.4018	0.074196	5.6198
1.4780	1.4037	0.074297	5.6274
1.4800	1.4056	0.074399	5.6349
1.4820	1.4075	0.074500	5.6425
1.4840	1.4094	0.074602	5.6501
1.4860	1.4113	0.074704	5.6576
1.4880	1.4132	0.074805	5.6652
1.4900	1.4151	0.074907	5.6728
1.4920	1.4170	0.075009	5.6803
1.4940	1.4189	0.075110	5.6879
1.4960	1.4208	0.075212	5.6955
1.4980	1.4227	0.075314	5.7030
1.5000	1.4246	0.075415	5.7106
1.5020	1.4265	0.075517	5.7182
1.5040	1.4284	0.075618	5.7257
1.5060	1.4303	0.075720	5.7333
1.5080	1.4322	0.075822	5.7408
1.5100	1.4341	0.075923	5.7484
1.5120	1.4360	0.076025	5.7560
1.5140	1.4379	0.076127	5.7635
1.5160	1.4398	0.076229	5.7711
1.5180	1.4417	0.076330	5.7787
1.5200	1.4436	0.076432	5.7862
1.5220	1.4455	0.076534	5.7938
1.5240	1.4474	0.076635	5.8013
1.5260	1.4493	0.076737	5.8089
1.5280	1.4512	0.076839	5.8165
1.5300	1.4531	0.076940	5.8240
1.5320	1.4550	0.077042	5.8316
1.5340	1.4569	0.077144	5.8391
1.5360	1.4588	0.077246	5.8467
1.5380	1.4607	0.077347	5.8543
1.5400	1.4625	0.077449	5.8618
1.5420	1.4644	0.077551	5.8694
1.5440	1.4663	0.077653	5.8769
1.5460	1.4682	0.077754	5.8845
1.5480	1.4701	0.077856	5.8921
1.5500	1.4720	0.077958	5.8996
1.5520	1.4739	0.078060	5.9072
1.5540	1.4758	0.078161	5.9147
1.5560	1.4777	0.078263	5.9223
1.5580	1.4796	0.078365	5.9299

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.5600	1.4815	0.078467	5.9374
1.5620	1.4834	0.078568	5.9450
1.5640	1.4853	0.078670	5.9525
1.5660	1.4872	0.078772	5.9601
1.5680	1.4891	0.078874	5.9676
1.5700	1.4910	0.078976	5.9752
1.5720	1.4929	0.079078	5.9827
1.5740	1.4948	0.079179	5.9903
1.5760	1.4967	0.079281	5.9979
1.5780	1.4986	0.079383	6.0054
1.5800	1.5005	0.079485	6.0130
1.5820	1.5024	0.079587	6.0205
1.5840	1.5043	0.079689	6.0281
1.5860	1.5062	0.079790	6.0356
1.5880	1.5081	0.079892	6.0432
1.5900	1.5100	0.079994	6.0508
1.5920	1.5119	0.080096	6.0583
1.5940	1.5138	0.080198	6.0659
1.5960	1.5157	0.080300	6.0734
1.5980	1.5176	0.080402	6.0810
1.6000	1.5195	0.080503	6.0885
1.6020	1.5214	0.080605	6.0961
1.6040	1.5233	0.080707	6.1036
1.6060	1.5252	0.080809	6.1112
1.6080	1.5271	0.080911	6.1187
1.6100	1.5290	0.081013	6.1263
1.6120	1.5309	0.081115	6.1338
1.6140	1.5328	0.081217	6.1414
1.6160	1.5347	0.081319	6.1489
1.6180	1.5366	0.081421	6.1565
1.6200	1.5385	0.081523	6.1640
1.6220	1.5404	0.081624	6.1716
1.6240	1.5423	0.081726	6.1791
1.6260	1.5442	0.081828	6.1867
1.6280	1.5461	0.081930	6.1942
1.6300	1.5480	0.082032	6.2018
1.6320	1.5499	0.082134	6.2093
1.6340	1.5518	0.082236	6.2169
1.6360	1.5537	0.082338	6.2244
1.6380	1.5556	0.082440	6.2320
1.6400	1.5575	0.082542	6.2395
1.6420	1.5594	0.082644	6.2471
1.6440	1.5613	0.082746	6.2546
1.6460	1.5632	0.082848	6.2622
1.6480	1.5650	0.082950	6.2697
1.6500	1.5669	0.083052	6.2773
1.6520	1.5688	0.083154	6.2848
1.6540	1.5707	0.083256	6.2924
1.6560	1.5726	0.083358	6.2999
1.6580	1.5745	0.083460	6.3075
1.6600	1.5764	0.083562	6.3150
1.6620	1.5783	0.083664	6.3226
1.6640	1.5802	0.083766	6.3301
1.6660	1.5821	0.083868	6.3377
1.6680	1.5840	0.083970	6.3452
1.6700	1.5859	0.084072	6.3528
1.6720	1.5878	0.084174	6.3603
1.6740	1.5897	0.084276	6.3679
1.6760	1.5916	0.084378	6.3754
1.6780	1.5935	0.084480	6.3829

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.6800	1.5954	0.034583	6.3905
1.6820	1.5973	0.084685	6.3980
1.6840	1.5992	0.084787	6.4056
1.6860	1.6011	0.084889	6.4131
1.6880	1.6030	0.084991	6.4207
1.6900	1.6049	0.085093	6.4282
1.6920	1.6068	0.085195	6.4358
1.6940	1.6087	0.085297	6.4433
1.6960	1.6106	0.085399	6.4508
1.6980	1.6125	0.085501	6.4584
1.7000	1.6144	0.085603	6.4659
1.7020	1.6163	0.085706	6.4735
1.7040	1.6182	0.085808	6.4810
1.7060	1.6201	0.085910	6.4886
1.7080	1.6220	0.086012	6.4961
1.7100	1.6239	0.086114	6.5036
1.7120	1.6258	0.086216	6.5112
1.7140	1.6277	0.086318	6.5187
1.7160	1.6296	0.086421	6.5263
1.7180	1.6315	0.086523	6.5338
1.7200	1.6334	0.086625	6.5413
1.7220	1.6353	0.086727	6.5489
1.7240	1.6372	0.086829	6.5564
1.7260	1.6391	0.086932	6.5640
1.7280	1.6410	0.087034	6.5715
1.7300	1.6429	0.087136	6.5790
1.7320	1.6448	0.087238	6.5866
1.7340	1.6467	0.087340	6.5941
1.7360	1.6486	0.087443	6.6017
1.7380	1.6505	0.087545	6.6092
1.7400	1.6524	0.087647	6.6167
1.7420	1.6543	0.087749	6.6243
1.7440	1.6561	0.087851	6.6318
1.7460	1.6580	0.087954	6.6393
1.7480	1.6599	0.088056	6.6469
1.7500	1.6618	0.088158	6.6544
1.7520	1.6637	0.088260	6.6620
1.7540	1.6656	0.088363	6.6695
1.7560	1.6675	0.088465	6.6770
1.7580	1.6694	0.088567	6.6846
1.7600	1.6713	0.088669	6.6921
1.7620	1.6732	0.088772	6.6996
1.7640	1.6751	0.088874	6.7072
1.7660	1.6770	0.088976	6.7147
1.7680	1.6789	0.089079	6.7222
1.7700	1.6808	0.089181	6.7298
1.7720	1.6827	0.089283	6.7373
1.7740	1.6846	0.089385	6.7448
1.7760	1.6865	0.039488	6.7524
1.7780	1.6884	0.089590	6.7599
1.7800	1.6903	0.089692	6.7674
1.7820	1.6922	0.089795	6.7750
1.7840	1.6941	0.089897	6.7825
1.7860	1.6960	0.089999	6.7900
1.7880	1.6979	0.090102	6.7976
1.7900	1.6998	0.090204	6.8051
1.7920	1.7017	0.090306	6.8126
1.7940	1.7036	0.090409	6.8202
1.7960	1.7055	0.090511	6.8277
1.7980	1.7074	0.090613	6.8352

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.8000	1.7093	0.090716	6.8428
1.8020	1.7112	0.090818	6.8503
1.8040	1.7131	0.090921	6.8578
1.8060	1.7150	0.091023	6.8654
1.8080	1.7169	0.091125	6.8729
1.8100	1.7188	0.091228	6.8804
1.8120	1.7207	0.091330	6.8879
1.8140	1.7226	0.091433	6.8955
1.8160	1.7245	0.091535	6.9030
1.8180	1.7264	0.091637	6.9105
1.8200	1.7283	0.091740	6.9181
1.8220	1.7302	0.091842	6.9256
1.8240	1.7321	0.091945	6.9331
1.8260	1.7340	0.092047	6.9406
1.8280	1.7358	0.092150	6.9482
1.8300	1.7377	0.092252	6.9557
1.8320	1.7396	0.092355	6.9632
1.8340	1.7415	0.092457	6.9708
1.8360	1.7434	0.092559	6.9783
1.8380	1.7453	0.092662	6.9858
1.8400	1.7472	0.092764	6.9933
1.8420	1.7491	0.092867	7.0009
1.8440	1.7510	0.092969	7.0084
1.8460	1.7529	0.093072	7.0159
1.8480	1.7548	0.093174	7.02[illegible]4
1.8500	1.7567	0.093277	7.0310
1.8520	1.7586	0.093379	7.0385
1.8540	1.7605	0.093482	7.0460
1.8560	1.7624	0.093584	7.0535
1.8580	1.7643	0.093687	7.0611
1.8600	1.7662	0.093790	7.0686
1.8620	1.7681	0.093892	7.0761
1.8640	1.7700	0.093995	7.0836
1.8660	1.7719	0.094097	7.0912
1.8680	1.7738	0.094200	7.0987
1.8700	1.7757	0.094302	7.1062
1.8720	1.7776	0.094405	7.1137
1.8740	1.7795	0.094507	7.1213
1.8760	1.7814	0.094610	7.1288
1.8780	1.7833	0.094713	7.1363
1.8800	1.7852	0.094815	7.1438
1.8820	1.7871	0.094918	7.1513
1.8840	1.7890	0.095020	7.1589
1.8860	1.7909	0.095123	7.1664
1.8880	1.7928	0.095226	7.1739
1.8900	1.7947	0.095328	7.1814
1.8920	1.7966	0.095431	7.1889
1.8940	1.7985	0.095533	7.1965
1.8960	1.8004	0.095636	7.2040
1.8980	1.8023	0.095739	7.2115
1.9000	1.8042	0.095841	7.2190
1.9020	1.8061	0.095944	7.2265
1.9040	1.8080	0.096047	7.2340
1.9060	1.8098	0.096149	7.2416
1.9080	1.8117	0.096252	7.2491
1.9100	1.8136	0.096355	7.2566
1.9120	1.8155	0.096457	7.2641
1.9140	1.8174	0.096560	7.2716
1.9160	1.8193	0.096663	7.2792
1.9180	1.8212	0.096765	7.2867

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
1.9200	1.8231	0.096868	7.2942
1.9220	1.8250	0.096971	7.3017
1.9240	1.8269	0.097073	7.3092
1.9260	1.8288	0.097176	7.3167
1.9280	1.8307	0.097279	7.3242
1.9300	1.8326	0.097382	7.3318
1.9320	1.8345	0.097484	7.3393
1.9340	1.8364	0.097587	7.3468
1.9360	1.8383	0.097690	7.3543
1.9380	1.8402	0.097793	7.3618
1.9400	1.8421	0.097895	7.3693
1.9420	1.8440	0.097998	7.3769
1.9440	1.8459	0.098101	7.3844
1.9460	1.8478	0.098204	7.3919
1.9480	1.8497	0.098306	7.3994
1.9500	1.8516	0.098409	7.4069
1.9520	1.8535	0.098512	7.4144
1.9540	1.8554	0.098615	7.4219
1.9560	1.8573	0.098718	7.4294
1.9580	1.8592	0.098820	7.4370
1.9600	1.8611	0.098923	7.4445
1.9620	1.8630	0.099026	7.4520
1.9640	1.8649	0.099129	7.4595
1.9660	1.8668	0.099232	7.4670
1.9680	1.8687	0.099335	7.4745
1.9700	1.8706	0.099437	7.4820
1.9720	1.8725	0.099540	7.4895
1.9740	1.8744	0.099643	7.4970
1.9760	1.8763	0.099746	7.5045
1.9780	1.8782	0.099849	7.5121
1.9800	1.8800	0.099952	7.5196
1.9820	1.8819	0.100054	7.5271
1.9840	1.8838	0.100157	7.5346
1.9860	1.8857	0.100260	7.5421
1.9880	1.8876	0.100363	7.5496
1.9900	1.8895	0.100466	7.5571
1.9920	1.8914	0.100569	7.5646
1.9940	1.8933	0.100672	7.5721
1.9960	1.8952	0.100775	7.5796
1.9980	1.8971	0.100878	7.5871
2.0000	1.8990	0.100981	7.5946
2.0020	1.9009	0.101084	7.6021
2.0040	1.9028	0.101186	7.6096
2.0060	1.9047	0.101289	7.6172
2.0080	1.9066	0.101392	7.6247
2.0100	1.9085	0.101495	7.6322
2.0120	1.9104	0.101598	7.6397
2.0140	1.9123	0.101701	7.6472
2.0160	1.9142	0.101804	7.6547
2.0180	1.9161	0.101907	7.6622
2.0200	1.9180	0.102010	7.6697
2.0220	1.9199	0.102113	7.6772
2.0240	1.9218	0.102216	7.6847
2.0260	1.9237	0.102319	7.6922
2.0280	1.9256	0.102422	7.6997
2.0300	1.9275	0.102525	7.7072
2.0320	1.9294	0.102628	7.7147
2.0340	1.9313	0.102731	7.7222
2.0360	1.9332	0.102834	7.7297
2.0380	1.9351	0.102937	7.7372

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
2.0400	1.9370	0.103040	7.7447
2.0420	1.9389	0.103143	7.7522
2.0440	1.9408	0.103246	7.7597
2.0460	1.9426	0.103349	7.7672
2.0480	1.9445	0.103453	7.7747
2.0500	1.9464	0.103556	7.7822
2.0520	1.9483	0.103659	7.7897
2.0540	1.9502	0.103762	7.7972
2.0560	1.9521	0.103865	7.8047
2.0580	1.9540	0.103968	7.8122
2.0600	1.9559	0.104071	7.8197
2.0620	1.9578	0.104174	7.8272
2.0640	1.9597	0.104277	7.8347
2.0660	1.9616	0.104380	7.8422
2.0680	1.9635	0.104483	7.8497
2.0700	1.9654	0.104587	7.8572
2.0720	1.9673	0.104690	7.8647
2.0740	1.9692	0.104793	7.8722
2.0760	1.9711	0.104896	7.8797
2.0780	1.9730	0.104999	7.8872
2.0800	1.9749	0.105102	7.8947
2.0820	1.9768	0.105205	7.9022
2.0840	1.9787	0.105309	7.9097
2.0860	1.9806	0.105412	7.9172
2.0880	1.9825	0.105515	7.9246
2.0900	1.9844	0.105618	7.9321
2.0920	1.9863	0.105721	7.9396
2.0940	1.9882	0.105825	7.9471
2.0960	1.9901	0.105928	7.9546
2.0980	1.9920	0.106031	7.9621
2.1000	1.9939	0.106134	7.9696
2.1020	1.9958	0.106238	7.9771
2.1040	1.9977	0.106341	7.9846
2.1060	1.9996	0.106444	7.9921
2.1080	2.0015	0.106547	7.9996
2.1100	2.0033	0.106650	8.0071
2.1120	2.0052	0.106754	8.0146
2.1140	2.0071	0.106857	8.0220
2.1160	2.0090	0.106960	8.0295
2.1180	2.0109	0.107064	8.0370
2.1200	2.0128	0.107167	8.0445
2.1220	2.0147	0.107270	8.0520
2.1240	2.0166	0.107374	8.0595
2.1260	2.0185	0.107477	8.0670
2.1280	2.0204	0.107580	8.0745
2.1300	2.0223	0.107683	8.0820
2.1320	2.0242	0.107787	8.0894
2.1340	2.0261	0.107890	8.0969
2.1360	2.0280	0.107993	8.1044
2.1380	2.0299	0.108097	8.1119
2.1400	2.0318	0.108200	8.1194
2.1420	2.0337	0.108303	8.1269
2.1440	2.0356	0.108407	8.1344
2.1460	2.0375	0.108510	8.1419
2.1480	2.0394	0.108613	8.1493
2.1500	2.0413	0.108717	8.1568
2.1520	2.0432	0.108820	8.1643
2.1540	2.0451	0.108924	8.1718
2.1560	2.0470	0.109027	8.1793
2.1580	2.0489	0.109131	8.1868

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
2.1600	2.0508	0.109234	8.1943
2.1620	2.0527	0.109337	8.2017
2.1640	2.0546	0.109441	8.2092
2.1660	2.0565	0.109544	8.2167
2.1680	2.0584	0.109647	8.2242
2.1700	2.0602	0.109751	8.2317
2.1720	2.0621	0.109854	8.2392
2.1740	2.0640	0.109958	8.2466
2.1760	2.0659	0.110061	8.2541
2.1780	2.0678	0.110165	8.2616
2.1800	2.0697	0.110268	8.2691
2.1820	2.0716	0.110372	8.2766
2.1840	2.0735	0.110475	8.2840
2.1860	2.0754	0.110579	8.2915
2.1880	2.0773	0.110682	8.2990
2.1900	2.0792	0.110786	8.3065
2.1920	2.0811	0.110889	8.3140
2.1940	2.0830	0.110993	8.3214
2.1960	2.0849	0.111096	8.3289
2.1980	2.0868	0.111200	8.3364
2.2000	2.0887	0.111303	8.3439
2.2020	2.0906	0.111407	8.3514
2.2040	2.0925	0.111510	8.3588
2.2060	2.0944	0.111614	8.3663
2.2080	2.0963	0.111717	8.3738
2.2100	2.0982	0.111821	8.3813
2.2120	2.1001	0.111924	8.3887
2.2140	2.1020	0.112028	8.3962
2.2160	2.1039	0.112131	8.4037
2.2180	2.1058	0.112235	8.4112
2.2200	2.1077	0.112339	8.4187
2.2220	2.1096	0.112442	8.4261
2.2240	2.1115	0.112546	8.4336
2.2260	2.1133	0.112650	8.4411
2.2280	2.1152	0.112753	8.4486
2.2300	2.1171	0.112857	8.4560
2.2320	2.1190	0.112960	8.4635
2.2340	2.1209	0.113064	8.4710
2.2360	2.1228	0.113168	8.4784
2.2380	2.1247	0.113271	8.4859
2.2400	2.1266	0.113375	8.4934
2.2420	2.1285	0.113479	8.5009
2.2440	2.1304	0.113582	8.5083
2.2460	2.1323	0.113686	8.5158
2.2480	2.1342	0.113790	8.5233
2.2500	2.1361	0.113893	8.5308
2.2520	2.1380	0.113997	8.5382
2.2540	2.1399	0.114101	8.5457
2.2560	2.1418	0.114205	8.5532
2.2580	2.1437	0.114308	8.5606
2.2600	2.1456	0.114412	8.5681
2.2620	2.1475	0.114516	8.5756
2.2640	2.1494	0.114620	8.5830
2.2660	2.1513	0.114723	8.5905
2.2680	2.1532	0.114827	8.5980
2.2700	2.1551	0.114931	8.6055
2.2720	2.1570	0.115034	8.6129
2.2740	2.1589	0.115138	8.6204
2.2760	2.1608	0.115242	8.6279
2.2780	2.1627	0.115346	8.6353

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
2.2800	2.1645	0.115450	8.6428
2.2820	2.1664	0.115553	8.6503
2.2840	2.1683	0.115657	8.6577
2.2860	2.1702	0.115761	8.6652
2.2880	2.1721	0.115865	8.6727
2.2900	2.1740	0.115969	8.6801
2.2920	2.1759	0.116072	8.6876
2.2940	2.1778	0.116176	8.6951
2.2960	2.1797	0.116280	8.7025
2.2980	2.1816	0.116384	8.7100
2.3000	2.1835	0.116488	8.7174
2.3020	2.1854	0.116592	8.7249
2.3040	2.1873	0.116695	8.7324
2.3060	2.1892	0.116799	8.7398
2.3080	2.1911	0.116903	8.7473
2.3100	2.1930	0.117007	8.7548
2.3120	2.1949	0.117111	8.7622
2.3140	2.1968	0.117215	8.7697
2.3160	2.1987	0.117319	8.7772
2.3180	2.2006	0.117423	8.7846
2.3200	2.2025	0.117527	8.7921
2.3220	2.2044	0.117631	8.7995
2.3240	2.2063	0.117735	8.8070
2.3260	2.2082	0.117839	8.8145
2.3280	2.2101	0.117942	8.8219
2.3300	2.2120	0.118046	8.8294
2.3320	2.2138	0.118150	8.8368
2.3340	2.2157	0.118254	8.8443
2.3360	2.2176	0.118358	8.8518
2.3380	2.2195	0.118462	8.8592
2.3400	2.2214	0.118566	8.8667
2.3420	2.2233	0.118670	8.8741
2.3440	2.2252	0.118774	8.8816
2.3460	2.2271	0.118878	8.8890
2.3480	2.2290	0.118982	8.8965
2.3500	2.2309	0.119086	8.9040
2.3520	2.2328	0.119190	8.9114
2.3540	2.2347	0.119294	8.9189
2.3560	2.2366	0.119398	8.9263
2.3580	2.2385	0.119502	8.9338
2.3600	2.2404	0.119606	8.9412
2.3620	2.2423	0.119711	8.9487
2.3640	2.2442	0.119815	8.9561
2.3660	2.2461	0.119919	8.9636
2.3680	2.2480	0.120023	8.9711
2.3700	2.2499	0.120127	8.9785
2.3720	2.2518	0.120231	8.9860
2.3740	2.2537	0.120335	8.9934
2.3760	2.2556	0.120439	9.0009
2.3780	2.2575	0.120543	9.0083
2.3800	2.2594	0.120647	9.0158
2.3820	2.2612	0.120751	9.0232
2.3840	2.2631	0.120856	9.0307
2.3860	2.2650	0.120960	9.0381
2.3880	2.2669	0.121064	9.0456
2.3900	2.2688	0.121168	9.0530
2.3920	2.2707	0.121272	9.0605
2.3940	2.2726	0.121376	9.0679
2.3960	2.2745	0.121480	9.0754
2.3980	2.2764	0.121585	9.0828

OBSERVED DISTANCE (INCHES)	TRUE DISTANCE (INCHES)	ERROR (INCHES)	RAY ANGLE (DEGREES)
2.4000	2.2783	0.121689	9.0903
2.4020	2.2802	0.121793	9.0977
2.4040	2.2821	0.121897	9.1052
2.4060	2.2840	0.122001	9.1126
2.4080	2.2859	0.122106	9.1201
2.4100	2.2878	0.122210	9.1275
2.4120	2.2897	0.122314	9.1350
2.4140	2.2916	0.122418	9.1424
2.4160	2.2935	0.122523	9.1498
2.4180	2.2954	0.122627	9.1573
2.4200	2.2973	0.122731	9.1647
2.4220	2.2992	0.122835	9.1722
2.4240	2.3011	0.122940	9.1796
2.4260	2.3030	0.123044	9.1871
2.4280	2.3049	0.123148	9.1945
2.4300	2.3067	0.123253	9.2020
2.4320	2.3086	0.123357	9.2094
2.4340	2.3105	0.123461	9.2168
2.4360	2.3124	0.123565	9.2243
2.4380	2.3143	0.123670	9.2317
2.4400	2.3162	0.123774	9.2392
2.4420	2.3181	0.123879	9.2466
2.4440	2.3200	0.123983	9.2541
2.4460	2.3219	0.124087	9.2615
2.4480	2.3238	0.124191	9.2689
2.4500	2.3257	0.124296	9.2764
2.4520	2.3276	0.124400	9.2838
2.4540	2.3295	0.124505	9.2913
2.4560	2.3314	0.124609	9.2987
2.4580	2.3333	0.124713	9.3061
2.4600	2.3352	0.124818	9.3136
2.4620	2.3371	0.124922	9.3210
2.4640	2.3390	0.125027	9.3285
2.4660	2.3409	0.125131	9.3359
2.4680	2.3428	0.125235	9.3433
2.4700	2.3447	0.125340	9.3508
2.4720	2.3466	0.125444	9.3582
2.4740	2.3484	0.125549	9.3657
2.4760	2.3503	0.125653	9.3731
2.4780	2.3522	0.125758	9.3805
2.4800	2.3541	0.125862	9.3880
2.4820	2.3560	0.125967	9.3954
2.4840	2.3579	0.126071	9.4028
2.4860	2.3598	0.126176	9.4103
2.4880	2.3617	0.126280	9.4177
2.4900	2.3636	0.126385	9.4251
2.4920	2.3655	0.126489	9.4326
2.4940	2.3674	0.126594	9.4400
2.4960	2.3693	0.126698	9.4474
2.4980	2.3712	0.126803	9.4549
2.5000	2.3731	0.126907	9.4623

APPENDIX C

APPLICATION OF COMPUTER PROGRAM "HOLOFER"

The computer program is an adptation of the inversion first proposed by C. D. Maldonado [9, 10, 11] and is designed to invert fringe numbers across a field to the density field. It can be operated in three different modes as described below:

(a) Mode 1

Mode 1 is utilized as a self-test of the computer program. It can either generate its own input density field using Subroutine FUNCT or read in a density field through Subroutine FREAD. The program then generates the fringe array and inverts the array back to the original density field. This mode was utilized in the present investigation to determine the value of the scale factor, α , required to obtain the correct density across the fin.

(b) Mode 2

This mode reads in irregularly spaced fringe data and generates the fringe array at regular intervals across the field using Subroutine SHEET. By specifying NCODE = 1, the fringe array can be generated by one of the functions in Subroutine FUNCT. Mode 2 was not utilized.

(c) Mode 3

Mode 3 reads in the fringe data at regularly spaced intervals and inverts the array to density data across the field. The Subroutine GARRAY calls Subroutine READ to read in the fringe data. The first two cards preceeding the fringe data provide the program with the fringe field size, location, and symmetry.

The following parameters were used in considering the symmetric field case:

PARAMETER	INPUT
NOF	Run Number
IMAX	201
JMAX	1
ISYM	101
JSYM	1
IMS	2
JMS	100
Z	0.387
XO	0.0
YO	0.0
PHISYM	0.0

References [3] and [12] contain further details and applications of the computer program. A print-out of the program is included in the next few pages of this appendix.

```
C                                                                       CAL00010
C     **************************HOLOVERT******************************* CAL00020
C                                                                       CAL00030
C     HOLOVERT INVERTS THE  FIELD AT AN ARRAY OF POINTS IN A VARIABLE   CAL00040
C     COORDINATE SYSTEM.  IT SURVEYS NPTS POINTS EACH FOR A SET OF NLINS CAL00050
C     LINES ACROSS THE FIELD.                                           CAL00060
C                                                                       CAL00070
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z   CAL00080
      COMMON /TAB/ INDEX,KEXTRA,MEXTRA,KLIMIT,MLIMIT,KOUT,MOUT          CAL00090
      COMMON /TAB2/ IPT,KPT,LPT,BND,NPTS,NLINS,RHOINF,RLAMDA,BETA       CAL00100
      COMMON /OUT/ XP,THEO,CALC,ERR,RHO,CA,FA                           CAL00110
      COMMON /EQPARA/ A,B,C,D,E,P,Q,S,T,U,V,W,RO,RA,NO,NA,NOF,NAF       CAL00120
      COMMON /SYM/ ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM                      CAL00130
      COMMON /IO/ CMS,IN1,IN2,IN4                                       CAL00140
      DATA BL,PL,ST,EX,OH,SC,DH,BR/1H ,1H+,1H*,1HX,1HO,1H:,1H-,1H|/     CAL00150
      DIMENSION RB(7),TL(62),RO(101),RA(101)                            CAL00160
C---------------------------------------------------------------------- CAL00170
      DIMENSION G(5151),GA(5151),H(202,5),SCF(73,6),BDA(4000)           CAL00180
      DIMENSION THEO(51,11),CALC(51,11),ERR(51),RHO(51)                 CAL00190
      DIMENSION CA(51),FA(51,11),AR(42),XP(51),YP(51)                   CAL00200
      CMS=0.
C---------------------------------------------------------------------- CAL00220
      REWIND 3
      IN1=5                                                             CAL00230
      IN2=5                                                             CAL00240
      IN4=5                                                             CAL00250
      IF (CMS.NE.1.) GO TO 20                                           CAL00260
      IN1=1                                                             CAL00270
      IN2=2                                                             CAL00280
      IN4=4                                                             CAL00290
      IF (CMS.EQ.1.) REWIND 4                                           CAL00300
20    READ (IN4,89) (AR(I),I=1,42)                                      CAL00310
      IMAX=AR(1)                                                        CAL00320
      JMAX=AR(2)*2.                                                     CAL00330
      IF (JMAX.LE.0) JMAX=1                                             CAL00340
      KLIMIT=AR(3)                                                      CAL00350
      MLIMIT=AR(4)                                                      CAL00360
      KEXTRA=AR(5)                                                      CAL00370
      MEXTRA=AR(6)                                                      CAL00380
      JSYM=AR(14)                                                       CAL00390
      ALPHA=AR(7)                                                       CAL00400
      SIZ =AR(8)                                                        CAL00410
      EPS=AR(9)                                                         CAL00420
      MODE=AR(13)                                                       CAL00430
      DGN=AR(17)                                                        CAL00440
      RHOINF=AR(10)                                                     CAL00450
      RLAMDA=AR(11)*1.E-8                                               CAL00460
      BETA=AR(12)                                                       CAL00470
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```
      NPTS=AR(15)                                                       CAL00480
      NLINS=AR(16)                                                      CAL00490
      SD=AR(18)                                                         CAL00500
      PHIZ=AR(19)                                                       CAL00510
      DELPHI=AR(20)                                                     CAL00520
      YPZERO=AR(21)                                                     CAL00530
      YPRNG=AR(22)                                                      CAL00540
      XPZERO=AR(23)                                                     CAL00550
      XPRNG=AR(24)                                                      CAL00560
      NOF=AR(25)                                                        CAL00570
      NAF=AR(26)                                                        CAL00580
      IPT=AR(27)                                                        CAL00590
      KPT=AR(28)                                                        CAL00600
      LPT=AR(29)                                                        CAL00610
      BND=AR(30)                                                        CAL00620
      A=AR(31)                                                          CAL00630
      B=AR(32)                                                          CAL00640
      C=AR(33)                                                          CAL00650
      D=AR(34)                                                          CAL00660
      E=AR(35)                                                          CAL00670
      P=AR(36)                                                          CAL00680
      S=AR(37)                                                          CAL00690
      T=AR(38)                                                          CAL00700
      U=AR(39)                                                          CAL00710
      V=AR(40)                                                          CAL00720
      W=AR(41)                                                          CAL00730
      Q=AR(42)                                                          CAL00740
      WRITE(6,90)
      WRITE(6,98)   (ST,I=1,75)
      WRITE(6,91)  (AR(I),I=1,6)
      WRITE(6,92)  (AR(I),I=7,12)
      WRITE(6,93)  (AR(I),I=13,18)
      WRITE(6,94)  (AR(I),I=19,24)
      WRITE(6,95)  (AR(I),I=25,30)
      WRITE(6,96)  (AR(I),I=31,36)
      WRITE(6,97)  (AR(I),I=37,42)
      WRITE(6,98)   (ST,I=1,75)
   90 FORMAT(/////, ' THE INPUT PARAME.ERS FOR THIS RUN ARE :',///)
   91 FORMAT (/5X,'*  IMAX   * JMAX/2  * KLIMIT  * MLIMIT  * KEXTRA  *',SET00310
     1' MEXTRA  *'/3X,6F10.0)
   92 FORMAT (/5X,'*  ALPHA  *  SIZE   *  EPS.   * RHO-INF * LAMBDA  *',SET00340
     1'  BETA   *'/3X,2F10.3,F11.6,2X,F8.7,F9.1,F11.6)                  SET
   93 FORMAT (/5X,'*  MODE   *  SYM.   * POINTS  *  LINES  * DIAGNOS *',SET00360
     1' STD.DEV *'/2X,5F10.0,F10.3)
   94 FORMAT (/5X,'* PHIZERO * DELPHI  * YPZERO  * YPRANGE * XPZERO  *',
     1' XPRANGE *'/4X,6F10.3)
   95 FORMAT (/5X,'* TST FUN * ADD FUN * GARRAY  *  GRAPH  * LIN PRT *',SET00400
     1' MAP BND *'/2X,6F10.0)
```

```
 96   FORMAT (/5X,'*    A    *    B    *    C    *    D    *    E    *',SET00420
     1'    P    *'/4X,6F10.3)
 97   FORMAT (/5X,'*    S    *    T    *    U    *    V    *    W    *',SET00440
     1'    Q    *'/4X,6F10.3)
 98   FORMAT (/3X,75A1)
      IF (DGN.GE.4) WRITE (6,89) (AR(I),I=1,42)                         CAL00750
      NNN=2                                                             CAL00760
      IF (MODE.LT.0) NNN=1                                              CAL00770
      IF (MODE.GT.5) NNN=3                                              CAL00780
      IF (MODE.GT.5) MODE=MODE-10                                       CAL00790
      NGP=0                                                             CAL00800
      IF (KLIMIT.LT.KEXTRA) KEXTRA=KLIMIT                               CAL00810
      IF (MLIMIT.LT.MEXTRA) MEXTRA=MLIMIT                               CAL00820
      IF (IPT.LT.0) NGP=IPT                                             CAL00830
      IF (IPT.LT.0) IPT=-IPT                                            CAL00840
      ISYM=2.1-(FLOAT(JSYM)/2.-FLOAT(JSYM/2))*2                         CAL00850
      IF (JSYM.EQ.0) ISYM=1                                             CAL00860
      IF (JSYM.GT.JMAX) ISYM=2                                          CAL00870
      IF (ISYM.EQ.1) JMAX=((JMAX+1)/2)*2                                CAL00880
      RJMX=JMAX                                                         CAL00890
      MSYM=JSYM                                                         CAL00900
      IF ((MSYM.EQ.0).OR.(MSYM.GT.JMAX)) MSYM=1                         CAL00910
      FCU=ISYM*JSYM*JMAX                                                CAL00920
      IF ((JSYM.GT.JMAX).OR.(JSYM.EQ.0)) FCU=JMAX                       CAL00930
      QSYM=FCU/RJMX                                                     CAL00940
      IMS=(IMAX+ISYM-1)/ISYM                                            CAL00950
      JMS=JMAX                                                          CAL00960
      IF (ISYM.EQ.1) JMS=(JMAX/2+1)/2                                   CAL00970
      IF (JSYM.EQ.0) JMS=JMAX/2                                         CAL00980
      MODE=ABS(AR(13))                                                  CAL00990
      XO=0.                                                             CAL01000
      YO=0.                                                             CAL01010
      ZD=0.                                                             CAL01020
      PHISYM=0.                                                         CAL01030
      HS=SIZE/2.                                                        CAL01040
      RHOS=1.286                                                        CAL01050
      BOX=RHOINF*BETA/RHOS/RLAMDA                                       CAL01060
      RPTS=NPTS                                                         CAL01070
      XPR=0.                                                            CAL01080
      IF (NPTS.GT.1) XPR=XPRNG/(RPTS-1.)/2.                             CAL01090
      XPM=-XPR                                                          CAL01100
      PIE=3.141592653589793                                             CAL01110
      MONE=1                                                            CAL01120
        WRITE (6,58) IMAX,JMAX,IMS,JMS,ISYM,JSYM,MSYM,QSYM,FCU          CAL01130
 58     FORMAT (3X,'IMAX,JMAX,IMS,JMS,ISYM,JSYM,MSYM,QSYM,FCU',/        CAL01140
     1   7I5,2F7.3/)                                                    CAL01150
      NTWO=2                                                            CAL01160
      IX=IMAX+JMAX                                                      CAL01170
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      NF=IN1                                                            CAL01180
      IF ((MODE.EQ.1.).AND.(NOF.EQ.8).AND.(DGN.GE.1.)) WRITE (6,69)     CAL01190
      IF ((MODE.EQ.1).AND.(NOF.EQ.8)) CALL FREAD (NO,RO,NF,ZD)          CAL01200
      Z=ZD                                                              CAL01210
      IF (DGN.GE.1.) WRITE (6,68)                                       CAL01220
      CALL GARRAY (G,GA,NOF,DGN,MONE,XO,YO,PHISYM)                      CAL01230
      LM=1                                                              CAL01240
      IF ((LPT.EQ.0).AND.(BND.EQ.0)) LM=0                               CAL01250
      IIMX=IMAX+1                                                       CAL01260
      JJMX=JMAX+1                                                       CAL01270
      IJMX=IMAX*JMAX                                                    CAL01280
      NBD=1                                                             CAL01290
      IF (JSYM.EQ.0) NBD=2                                              CAL01300
      KBD=KLIMIT*NBD                                                    CAL01310
      DO 15 IJ=1,IJMX                                                   CAL01320
   15 GA(IJ)=0.                                                         CAL01330
      IF (NAF.EQ.0) GO TO 16                                            CAL01340
      NF=IN2                                                            CAL01350
      IF ((NAF.EQ.8).AND.(DGN.GE.1.)) WRITE (6,69)                      CAL01360
      IF (NAF.EQ.8) CALL FREAD (NA,RA,NF,ZD)                            CAL01370
      MST=MODE                                                          CAL01380
      MODE=1                                                            CAL01390
      IF (DGN.GE.1.) WRITE (6,68)                                       CAL01400
      IF (NAF.NE.0) CALL GARRAY (GA,G,NAF,DGN,NTWO,XO,YO,PHISYM)        CAL01410
      MODE=MST                                                          CAL01420
      DO 6 IJ=1,IJMX                                                    CAL01430
    6 G(IJ)=G(IJ)+GA(IJ)                                                CAL01440
   16 RLINS=NLINS                                                       CAL01450
      IF (NAF.EQ.8) WRITE (6,88) NA,(RA(L),L=1,NA)                      CAL01460
      IF (NOF.EQ.8) WRITE (6,87) NO,(RO(I),I=1,NO)                      CAL01470
      IF (LM.EQ.0) GO TO 14                                             CAL01480
      RB(1)=-1.                                                         CAL01490
      DO 1 I=2,7                                                        CAL01500
    1 RB(I)=RB(I-1)+.5                                                  CAL01510
      TPIE=2.*PIE                                                       CAL01520
      MPIE=-PIE                                                         CAL01530
      DYP=0.                                                            CAL01540
      DXP=0.                                                            CAL01550
      IF (NLINS.GT.1) DYP=YPRNG/(RLINS-1.)                              CAL01560
      IF (NPTS.GT.1) DXP=XPRNG/(RPTS-1.)                                CAL01570
      IF ((DGN.GE.1.).AND.(NNN.EQ.2)) WRITE (6,64)                      CAL01580
      IF(NNN.EQ.2) CALL BDGEN (G,H,SCF,DGN,NBD,BDA,KBD)                 CAL01590
      DO 5 J=1,NLINS                                                    CAL01600
      IF (DGN.GE.1.) WRITE (6,67) J                                     CAL01610
      RJM=J-1                                                           CAL01620
      PHI=PHIZ+DELPHI*RJM                                               CAL01630
      YP(J)=YPZERO+DYP*RJM                                              CAL01640
      PSI=(PHI+90.)*PIE/180.                                            CAL01650
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      TAU=PSI-PHISYM                                                    CAL01660
      IF (LPT.EQ.0) GO TO 9                                             CAL01670
      IF (LPT.LE.1) WRITE (6,78) (ST,I=1,124)                           CAL01680
      IF (LPT.GT.1) WRITE (6,74) (ST,I=1,95)                            CAL01690
      IF ((CMS.EQ.1.).AND.(LPT.GT.1)) READ (5,79) ZZ                    CAL01700
      WRITE (6,86)                                                      CAL01710
      WRITE (6,85) Z,PHI,YP(J)                                          CAL01720
      WRITE (6,76)                                                      CAL01730
      IF (MODE.EQ.1) WRITE (6,83) (RB(I),I=1,7)                         CAL01740
      IF (MODE.GT.1) WRITE (6,80) (RB(I),I=1,7)                         CAL01750
      WRITE (6,81) (DH,I=1,54),(PL,II=1,13)                             CAL01760
    9 IC=0                                                              CAL01770
      DO 3 I=1,NPTS                                                     CAL01780
      RIM=I-1                                                           CAL01790
      THEO(I,J)=0.                                                      CAL01800
      CA(I)=0.                                                          CAL01810
      FA(I,J)=0.                                                        CAL01820
      ERR(I)=0.                                                         CAL01830
      CALC(I,J)=0.                                                      CAL01840
      RHO(I)=0.                                                         CAL01850
      XP(I)=XPZERO+DXP*RIM                                              CAL01860
      XPII=ABS(XP(I))                                                   CAL01870
      IF (XPII.LT.1.E-10) XP(I)=0.                                      CAL01880
      RS=SQRT(XP(I)**2+YP(J)**2)/HS                                     CAL01890
      IF (RS.GT.1.) GO TO 13                                            CAL01900
      THT=ATANM(YP(J),XP(I))                                            CAL01910
      IF (XPII.EQ.0.) THT=0.                                            CAL01920
      SIG=TAU-PIE/2.+THT                                                CAL01930
      IF (SIG.GT.PIE) SIG=SIG-TPIE                                      CAL01940
      IF (SIG.LT.MPIE) SIG=SIG+TPIE                                     CAL01950
      SIGI=SIG                                                          CAL01960
      XS=RS*COS(SIG)                                                    CAL01970
      IF (DGN.GE.1.) WRITE (6,44) SIG                                   CAL01980
   44 FORMAT ('    SIG=',E10.3)                                         CAL01990
      YS=RS*SIN(SIG)                                                    CAL02000
      IF(DGN.GE.5) WRITE (6,57) PHI,DELPHI,PSI,TAU,THT,SIG,SIGI,XS,YS   CAL02010
   57   FORMAT ('  ANGLES=',10E10.3)                                    CAL02020
      RI=I                                                              CAL02030
      F=0.                                                              CAL02040
      IF (DGN.GE.2.) WRITE (6,66) I                                     CAL02050
      CALL FUNCT (XS,YS,FA(I,J),NAF,DGN,NTWO)                           CAL02060
      IF (MODE.EQ.1) CALL FUNCT (XS,YS,F,NOF,DGN,MONE)                  CAL02070
      THEO(I,J)=F                                                       CAL02080
      IF (NNN.GE.2) REWIND 3                                            CAL02090
      IF(NNN.GE.2) CALL FIELD (RS,SIGI,SOLN,NBD,BDA,DGN,KBD)            CAL02100
      IF(NNN.EQ.1) CALL FIELD2 (RS,SIGI,SOLN,G,H,SCF,DGN)               CAL02110
      CA(I)=SOLN/BOX/HS                                                 CAL02120
      CALC(I,J)=CA(I)-FA(I,J)                                           CAL02130
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      RHO(I)=RHOINF*(CALC(I,J)+1.)                                      CAL02140
      ERR(I)=CA(I)                                                      CAL02150
      IF (MODE.EQ.1) ERR(I)=(CALC(I,J)-THEO(I,J))                       CAL02160
      IF (MODE.GT.1) THEO(I,J)=FA(I,J)                                  CAL02170
      IF (LPT.EQ.0) GO TO 3                                             CAL02180
13    LC=0                                                              CAL02190
      TL(1)=BL                                                          CAL02200
      TTL=0.                                                            CAL02210
      IF ((XP(I).GT.XPM).AND.(XP(I).LT.XPR)) TTL=1.
      IF (IC.EQ.5) IC=0
      IF (IC.EQ.0) TL(1)=PL
      DO 2 L=2,62
      TL(L)=BL                                                          CAL02260
      IF ((I.EQ.1).OR.(TTL.EQ.1.).OR.(I.EQ.NPTS)) TL(L)=PL              CAL02270
      IF (LC.EQ.10) LC=0                                                CAL02280
      IF ((IC.EQ.0).AND.(LC.EQ.0)) TL(L)=PL                             CAL02290
2     LC=LC+1                                                           CAL02300
      TL(2)=PL                                                          CAL02310
      TL(22)=PL                                                         CAL02320
      TL(62)=PL                                                         CAL02330
      IC=IC+1                                                           CAL02340
      RLW=(CA(I)+1.)*20.+2.5                                            CAL02350
      LW=RLW                                                            CAL02360
      IF (LW.GT.62) LW=62                                               CAL02370
      IF (LW.LT.2) LW=2                                                 CAL02380
      TL(LW)=SC                                                         CAL02390
      RLY=(FA(I,J)+1.)*20.+2,5                                          CAL02400
      LY=RLY                                                            CAL02410
      IF (LY.GT.62) LY=62                                               CAL02420
      IF (LY.LT.2) LY=2                                                 CAL02430
      IF (NAF.NE.0) TL(LY)=ST                                           CAL02440
      RLX=(THEO(I,J)+1.)*20.+2.5                                        CAL02450
      LX=RLX                                                            CAL02460
      IF (LX.GT.62) LX=62                                               CAL02470
      IF (LX.LT.2) LX=2                                                 CAL02480
      IF (MODE.EQ.1) TL(LX)=OH                                          CAL02490
      RLZ=(CALC(I,J)+1.)*20.+2.5                                        CAL02500
      LZ=RLZ                                                            CAL02510
      IF (LZ.GT.62) LZ=62                                               CAL02520
      IF (LZ.LT.2) LZ=2                                                 CAL02530
      TL(LZ)=EX                                                         CAL02540
      WRITE (6,82)MOUT,KOUT,INDEX,THEO(I,J),ERR(I),CALC(I,J),RHO(I),    CAL02550
     1XP(I),(TL(L),L=1,62)                                              CAL02560
      IF ((NPTS.LE.20).AND.(I.NE.NPTS)) WRITE (6,79)                    CAL02570
3     CONTINUE                                                          CAL02580
      IF (LPT.NE.0) WRITE (6,81) (DH,I=1,54),(PL,I=1,13)                CAL02590
      TMAX=0.                                                           CAL02600
      TMIN=0.                                                           CAL02610
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      IE=0                                                              CAL02620
      BE=0.                                                             CAL02630
      EB=0.                                                             CAL02640
      DO 4 I=1,NPTS                                                     CAL02650
      TH=THEO(I,J)                                                      CAL02660
      IF (TH.GT.TMAX) TMAX=TH                                           CAL02670
      IF (TH.LT.TMIN) TMIN=TH                                           CAL02680
      ER=ABS(CALC(I,J)-TH)                                              CAL02690
      IF (ER.LE.BE) GO TO 4                                             CAL02700
      BE=ER                                                             CAL02710
      IE=I                                                              CAL02720
    4 CONTINUE                                                          CAL02730
      TMM=TMAX-TMIN                                                     CAL02740
      EB=RHOINF*(CALC(IE,J)-THEO(IE,J))                                 CAL02750
      IF (TMM.NE.0.) BE=(CALC(IE,J)-THEO(IE,J))*100./TMM                CAL02760
      IF ((MODE.EQ.1).AND.(LPT.NE.0)) WRITE (6,75) EB,XP(IE),BE         CAL02770
      IF (DELPHI.NE.0.) YP(J)=PHI                                       CAL02780
    5 CONTINUE                                                          CAL02790
      IF (BND.EQ.0.) GO TO 14                                           CAL02800
      IF (LPT.EQ.1) WRITE (6,78) (ST,I=1,124)                           CAL02810
      IF (LPT.GT.1) WRITE (6,74) (ST,I=1,95)                            CAL02820
      IF ((CMS.EQ.1.).AND.(LPT.GT.1)) READ (5,79) ZZ                    CAL02830
      IF (DGN.GE.1.) WRITE (6,63)                                       CAL02840
      CALL MAP (NPTS,NLINS,CALC,NOF,Z,BND)                              CAL02850
   14 IF (NAF.EQ.0) GO TO 10                                            CAL02860
      NAO=10*NOF+NAF                                                    CAL02870
      IF ((DGN.GE.1.).AND.(NGP.EQ.-3)) WRITE (6,62)                     CAL02880
      IF (NGP.EQ.-3) CALL GPUNCH (Z,XO,YO,PHISYM,NAO,IMAX,JMAX,G)       CAL02890
      DO 7 IJ=1,IJMX                                                    CAL02900
    7 G(IJ)=G(IJ)-GA(IJ)                                                CAL02910
   10 IF (IPT.LE.0) GO TO 11                                            CAL02920
      IF ((IPT.EQ.1).OR.(IPT.EQ.3)) WRITE (6,78) (ST,I=1,124)           CAL02930
      IF ((IPT.EQ.2).OR.(IPT.GE.4)) WRITE (6,74) (ST,I=1,95)            CAL02940
      IF ((CMS.EQ.1.).AND.((IPT.EQ.2).OR.(IPT.GE.4))) READ (5,79) ZZ    CAL02950
      CALL GPRINT (G,MONE)                                              CAL02960
      IF (NGP.EQ.-1) CALL GPUNCH (Z,XO,YO,PHISYM,NOF,IMAX,JMAX,G)       CAL02970
      IF (IPT.EQ.3) WRITE (6,78) (ST,I=1,124)                           CAL02980
      IF (IPT.CE.4) WRITE (6,74) (ST,I=1,95)                            CAL02990
      IF ((CMS.EQ.1.).AND.(IPT.GE.4)) READ (5,79) ZZ                    CAL03000
      IF (IPT.GE.3) CALL CPRINT (GA,NTWO)                               CAL03010
   11 IF (KPT.LE.0) GO TO 12                                            CAL03020
      IF ((KPT.EQ.1).OR.(KPT.EQ.3)) WRITE (6,78) (ST,I=1,124)           CAL03030
      IF ((KPT.EQ.2).OR.(KPT.GE.4)) WRITE (6,74) (ST,I=1,95)            CAL03040
      IF ((CMS.EQ.1.).AND.((KPT.EQ.2).OR.(KPT.GE.4))) KEAD (5,79) ZZ    CAL03050
      IF (DGN.GE.1.) WRITE (6,61)                                       CAL03060
      CALL GPLOT (G,GA,JMS)                                             CAL03070
   12 WRITE (6,78) (EX,I=1,124)                                         CAL03080
      AGAIN=ST                                                          CAL03090
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      IF (CMS.NE.1.) READ(5,60) AGAIN                                   CAL03100
      IF (AGAIN.EQ.BL) GO TO 20                                         CAL03110
      WRITE (6,77)                                                      CAL03120
89    FORMAT (6F12.7)                                                   CAL03130
88    FORMAT (/'      THE INPUT DATA FOR ADD-ON FUNCTION NO.8 (',I3,    CAL03140
     1' POINTS) WAS:'/7(11F10.3/))                                      CAL03150
87    FORMAT (/'      THE INPUT DATA FOR THE TEST FUNCTION NO.8, (',I3, CAL03160
     1' POINTS) WAS:'/7(11F10.3/))                                      CAL03170
86    FORMAT (1H1//'    THE INVERTED CROSS SECTION FOR:')               CAL03180
85    FORMAT (10X,'Z  =',F8.3,' CM.'/10X,'PHI=',F8.3,' DEGREES'/10X,    CAL03190
     14HY' =,F8.3,' CM.',44X,'O = ORIGINAL FUNCTION'/                   CAL03200
     270X,'* = ADD-ON FUNCTION')                                        CAL03210
84    FORMAT (' ADJUST PAGE, HIT SPACE AND RETURN.')                    CAL03220
83    FORMAT ('    LIMIT  MAX  ORIGINAL      ABS.  COMPUTED (MG/CC)'/' MCAL03230
     1   K TERM  FUNCTION     ERROR  FUNCTION DENSITY ',6H   X'  ,F4.1, CAL03240
     26F10.1)                                                           CAL03250
82    FORMAT (2X,I2,1X,I3,1X,I4,1X,F9.4,2X,F7.3,1X,F9.4,1X,F7.3,        CAL03260
     1F7.3,1X,62A1)                                                     CAL03270
81    FORMAT (3X,54A1,2X,A1,12(4X,A1))                                  CAL03280
80    FORMAT ('    LIMIT  MAX',3X,'ADD-ON',6X,'THE',4X,'DENSITY (MG/CC)'/CAL03290
     1'  M    K TERM',2X,'FUNCTION',5X,'SUM',3X,'FUNCTION DENSITY ',    CAL03300
     26H   X'  ,F4.1,6F10.1)                                            CAL03310
79    FORMAT (1X,F10.3)                                                 CAL03320
78    FORMAT (1X,124A1)                                                 CAL03330
77    FORMAT (1X//)                                                     CAL03340
76    FORMAT (4X,'FUNCTION = (RHO/RHO-INFINITY)-1.0',33X,': = THE'      CAL03350
     1,' INVERTED SUM'/70X,'X = COMPUTED FUNCTION')                     CAL03360
75    FORMAT ('       LARGEST ERROR: ',F8.6,' GMS/CC:      AT ',3HX'=,F6.3CAL03370
     1,':',4X,F10.2,' PERCENT.'//)                                      CAL03380
74    FORMAT (1X,47A1,' SET PAGE, HIT SPACE, RETURN ',48A1)             CAL03390
69    FORMAT ('   CALL FREAD')                                          CAL03400
68    FORMAT ('   CALL GARRAY')                                         CAL03410
67    FORMAT ('   LINE',I3,' DO LOOP')                                  CAL03420
66    FORMAT ('   POINT',I3,' CALL FUNCT')                              CAL03430
65    FORMAT ('   CALL FIELD')                                          CAL03440
64    FORMAT ('   CALL BDGEN')                                          CAL03450
63    FORMAT ('   CALL MAP')                                            CAL03460
62    FORMAT ('   CALL GPUNCH')                                         CAL03470
61    FORMAT ('   CALL GPLOT')                                          CAL03480
60    FORMAT (80A1)                                                     CAL03490
      STOP                                                              CAL03500
      END                                                               CAL03510
                                                                        CAL03520
C000001                                                                 SUB00010
C                                                                       SUB00020
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      SUBROUTINE BDGEN (G,H,SCF,DGN,NBD,BDA,KBD)
C
C     BDGEN EVALUATES THE B AND D COEFFICIENTS FOR ALL M AND K, AND WRITES
C     THE ARRAY LINEARLY ON DISK.
C
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z
      COMMON /TAB/ INDEX,KEXTRA,MEXTRA,KLIMIT,MLIMIT,KOUT,MOUT
      COMMON /SYM/ ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM
      DIMENSION G(IJMX),H(IIMX,5),SCF(JJMX,6),BDA(KBD)
C     INITIALIZE THE VALUES:
      INDEX=0
      KL2=NBD*KLIMIT
      REWIND 3
      JJMX6=JJMX*6
      IIMX2=(IIMX+1)/2
      PIE=3.141592653589793
      RIMAX=IMAX
      KLMP=KLIMIT+1
      DX=2./RIMAX
      RJMAX=JMAX
      DXI=2.*PIE/FCU
C     INITIALIZE THE MODIFIED HERMITE POLYNOMIAL ARRAY:  VECTORS:
C     (1)=H1, (2)=H2, (3)=ALPHA*X(I), (4)=HM+2 STORED, (5)=HM+1 STORED
      DO 1 II=1,IIMX2
      RII=II
      IIM=IIMX-II+1
      H(II,3)=ALPHA*(RII*DX-DX-1.)
      H(IIM,3)=-H(II,3)
      H(II,1)=2.*H(II,3)
      H(II,2)=(H(II,3)*H(II,1)-1.)/3.
      H(IIM,1)=-H(II,1)
      H(IIM,2)=H(II,2)
      H(II,5)=H(II,2)
      H(IIM,5)=H(IIM,2)
      H(II,4)=H(II,1)
    1 H(IIM,4)=H(IIM,1)
      SIGN=1.
C     INITIATE THE SIN/COS ARRAY:
      DO 2 J=1,JJMX
      RJM=J-1
      SCF(J,1)=0.
      SCF(J,2)=1.
      SCF(J,3)=SIN(RJM*DXI-PIE/2.)
      SCF(J,4)=COS(RJM*DXI-PIE/2.)
      SCF(J,5)=0.
    2 SCF(J,6)=0.
      MS=0
C     COMMENCE THE M LOOP:
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      DO 7 MP=1,MLIMIT                                                  SUB00510
      M=MP-1                                                            SUB00520
      RM=M                                                              SUB00530
      SIGN=-SIGN                                                        SUB00540
      IF (DGN.LE.-4) WRITE (6,88) SCF(1,1),SCF(2,1),SCF(1,2),SCF(2,2)   SUB00550
C   TEST FOR SYMMETRY SKIPS:                                            SUB00560
      IF (MS.EQ.MSYM) MS=0                                              SUB00570
      TOTAL=0.                                                          SUB00580
      MS=MS+1                                                           SUB00590
      IF (MS.NE.1) GO TO 6                                              SUB00600
C   COMMENCE THE K LOOP:                                                SUB00610
      DO 5 KP=1,KLIMIT                                                  SUB00620
      K=KP-1                                                            SUB00630
      PK=KP                                                             SUB00640
      RK=K                                                              SUB00650
      INDEX=INDEX+1                                                     SUB00660
C   CALL THE B & D COEFFICIENTS AND WRITE THEM ON DISK:                 SUB00670
      CALL BD (M,K,G,H,SCF,B,D,JJMX6)                                   SUB00680
      IF(DGN.EQ.3.) WRITE(6,89) M,K,B,D
      IF (DGN.LE.-2) WRITE (6,89) M,K,B,D                               SUB00690
      IF (DGN.LE.-4) WRITE (6,88) H(1,1),H(1,2),H(1,4),H(1,5)           SUB00700
      KK=K*NBD+1                                                        SUB00710
      K2=KP*NBD                                                         SUB00720
      BDA(K2)=D                                                         SUB00730
      BDA(KK)=B                                                         SUB00740
C   GENERATE THE NEXT ORDER OF THE SET OF HERMITE POLYNOMIALS FOR NEW K:SUB00750
      ORDER=M+2*KP+1                                                    SUB00760
      HA=SQRT(PK*(PK+RM))/ORDER                                         SUB00770
      HB=2.*SQRT((PK+1.)*(RM+PK+1.))/(ORDER+1.)/(ORDER+2.)              SUB00780
      DO 5 II=1,IIMX2                                                   SUB00790
      IIM=IIMX-II+1                                                     SUB00800
      H(II,1)=2.*(H(II,3)*H(II,2)-HA*H(II,1))                           SUB00810
      H(IIM,1)=SIGN*H(II,1)                                             SUB00820
5     H(II,2)=HB*(H(II,3)*H(II,1)-ORDER*H(II,2))                        SUB00830
C   ADVANCE THE SIN/COS ARRAY FOR THE NEXT M:                           SUB00840
      DO 3 J=1,JJMX                                                     SUB00850
      IF (DGN.LE.-5) WRITE (6,87) (SCF(J,NT),NT=1,6)                    SUB00860
87       FORMAT ('  SIN/COS MXI:'8E10.3)                                SUB00870
      STEMP=SCF(J,1)                                                    SUB00880
      SCF(J,1)=SCF(J,1)*SCF(J,4)+SCF(J,2)*SCF(J,3)                      SUB00890
3     SCF(J,2)=SCF(J,2)*SCF(J,4)-STEMP*SCF(J,3)                         SUB00900
      DO 4 J=1,JMAX                                                     SUB00910
      SCF(J,5)=SCF(J+1,1)-SCF(J,1)                                      SUB00920
4     SCF(J,6)=SCF(J+1,2)-SCF(J,2)                                      SUB00930
      WRITE (3) (BDA(I),I=1,KBD)                                        SUB00940
      IF (DGN.LE.-3) WRITE (6,88) (BDA(I),I=1,10)                       SUB00950
      IF (JSYM.GT.JMAX) RETURN                                          SUB00960
6     RM=RM+1                                                           SUB00970
```

```
C     REGENERATE THE HERMITE ARRAY FOR NEW M, K=0:
        DO 7 II=1,IIMX2
          IIM=IIMX-II+1
          H(II,2)=H(II,4)*SQRT(RM)/(RM+1.)
          H(II,1)=H(II,5)*(RM+2.)
          H(IIM,1)=-SIGN*H(II,1)
          H(II,2)=2.*SQRT(RM+1)*(H(II,3)*H(II,1)-(RM+1.)*H(II,2))
          H(II,2)=H(II,2)/(RM+2.)/(RM+3.)
          H(II,4)=H(II,1)
7         H(II,5)=H(II,2)
89      FORMAT ('    M=',I4,',     K=',I4,',     B=',E10.4,',     D=',E10.4)
88      FORMAT (2X,10E10.3)
        RETURN
        END
C000002
C

        SUBROUTINE FIELD (RS,SIG,SOLN,NBD,BDA,DGN,KBD)
C
C     FIELD EVALUATES THE VALUE OF THE FIELD FUNCTION AT A PARTICULAR
C     POINT DESIGNATED IN CYLINDRICAL COORDINATES, BY USING THE INVERSION
C     EQUATION OF MALDONADO, ET.AL.  FIELD USES THE ARRAY OF  B & D
C     COEFFICIENTS GENERATED IN SUBROUTINE BDGEN.
C
        COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z
        COMMON /TAB/ INDEX,KEXTRA,MEXTRA,KLIMIT,MLIMIT,KOUT,MOUT
        COMMON /SYM/ ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM
        DIMENSION BDA(KBD), STK(52), STM(52)
C     INITIALIZE THE VALUES:
        INDEX=0
        MTIMER=0
        KOUT=0
        MOUT=0
        MMAX=0
        KMAX=0
        TOTAL=0.
        JJMX6=JJMX*6
        REWIND 3
        AR=ALPHA*RS
        ARG=AR**2
        EXPON=EXP(-ARG)
        PIE=3.141592653589793
        APP=ALPHA/PIE/PIE
        M=0
        RM=M
        RIMAX=IMAX
        DX=2./RIMAX
```

```
      RJMAX=JMAX                                                        SUB01440
      SIGN=1.                                                           SUB01450
      STK(1)=0.                                                         SUB01460
      STM(1)=0.                                                         SUB01470
      SMS=0.                                                            SUB01480
      CMS=1.                                                            SUB01490
      SMI=SIN(SIG)                                                      SUB01500
      CMI=COS(SIG)                                                      SUB01510
      MEP=MEXTRA+1                                                      SUB01520
      DO 16 MB=1,MEP                                                    SUB01530
16    STM(MB)=0.                                                        SUB01540
      FM=1.                                                             SUB01550
      MS=0                                                              SUB01560
C   COMMENCE THE M LOOP:                                                SUB01570
2     SIGN=-SIGN                                                        SUB01580
      K=0                                                               SUB01590
      RK=K                                                              SUB01600
      RM=M                                                              SUB01610
      ARM=1.                                                            SUB01620
      IF (M.NE.0) ARM=AR**M                                             SUB01630
      KTIMER=0                                                          SUB01640
      KEP=KEXTRA+1                                                      SUB01650
      DO 15 KB=1,KEP                                                    SUB01660
15    STK(KB)=0.                                                        SUB01670
      SIGNK=-1.                                                         SUB01680
C   COMPUTE THE K=0 & K=1 ORDERS OF LAGUERRE POLYNOMIAL FOR GIVEN M:    SUB01690
      PM=0.                                                             SUB01700
      P=SQRT(1./FM)                                                     SUB01710
      PP=(RM+1.-ARG)*SQRT(1./FM/(RM+1.))                                SUB01720
C   TEST FOR SYMMETRY SKIPS:                                            SUB01730
      IF (MS.EQ.MSYM) MS=0                                              SUB01740
      MS=MS+1                                                           SUB01750
      IF (MS.NE.1) GO TO 7                                              SUB01760
C   READ A LINE OF B & D COEFFICIENTS FOR GIVEN M:                      SUB01770
      READ (3) (BDA(I),I=1,KBD)                                         SUB01780
      IF (DGN.LE.-6) WRITE (6,88) (BDA(I),I=1,10)                       SUB01790
C   COMMENCE THE K LOOP:                                                SUB01800
3     INDEX=INDEX+1                                                     SUB01810
      SIGNK=-SIGNK                                                      SUB01820
C   COMPUTE THE M,K SUMMATION TERM:                                     SUB01830
      KK=K*NBD+1                                                        SUB01840
      B=BDA(KK)                                                         SUB01850
      D=0.                                                              SUB01860
      IF (NBD.EQ.2) D=BDA(KK+1)                                         SUB01870
      BRAKET=B                                                          SUB01880
      IF(RM.EQ.0.) GO TO 4                                              SUB01890
      BRAKET=B*CMS+D*SMS                                                SUB01900
4     ADD=SIGNK*BRAKET*P*ARM                                            SUB01910
```

```
      TOTAL=TOTAL+ADD                                                   SUB01920
      IF (DGN.GT.-5) GO TO 5                                            SUB01930
      STOT=TOTAL*EXPON*APP/BOX/SIZE                                     SUB01940
      WRITE (6,89) M,K,STOT,ADD,BRAKET,P,ARM,B,CMS,D,SMS                SUB01950
C   ESTABLISH CHECK AS THE RELATIVE SIZE OF THE M,K TERM OF THE SERIES: SUB01960
5     CHECK=ABS(ADD)                                                    SUB01970
      IF (TOTAL.GT.EPS) CHECK=ABS(ADD/TOTAL)                            SUB01980
C   ADVANCE THE K INDEX:                                                SUB01990
      K=K+1                                                             SUB02000
      RK=K                                                              SUB02010
      DO 10 KA=1,KEXTRA                                                 SUB02020
      KB=KEXTRA-KA+1                                                    SUB02030
10    STK(KB+1)=STK(KB)                                                 SUB02040
      STK(2)=TOTAL                                                      SUB02050
      ORDER=M+2*K+1                                                     SUB02060
C   GENERATE THE NEXT ORDER OF LAGUERRE POLYNOMIAL FOR NEW K:           SUB02070
      PM=P                                                              SUB02080
      P=PP                                                              SUB02090
      PP=P*(ORDER-ARG)-PM*SQRT(RK*(RM+RK))                              SUB02100
      PP=PP/SQRT((RK+1.)*(RM+RK+1.))                                    SUB02110
C   SET K TIMER TO PROVIDE EXTRA K TERMS AFTER CHECK < EPS:             SUB02120
      KTIMER=KTIMER+1                                                   SUB02130
      IF (K.GE.KLIMIT) GO TO 6                                          SUB02140
      IF (CHECK.GE.EPS) KTIMER=0                                        SUB02150
      IF (KTIMER.LE.KEXTRA) GO TO 3                                     SUB02160
      GO TO 7                                                           SUB02170
6     KOUT=KOUT+1                                                       SUB02180
      IF (KEXTRA.EQ.0) GO TO 7                                          SUB02190
      TOTAL=0.                                                          SUB02200
      DO 11 KA=1,KEXTRA                                                 SUB02210
11    TOTAL=TOTAL+STK(KA+1)                                             SUB02220
      RKX=KEXTRA                                                        SUB02230
      TOTAL=TOTAL/RKX                                                   SUB02240
C   END OF K LOOP:  ADVANCE M:                                          SUB02250
7     M=M+1                                                             SUB02260
      RM=M                                                              SUB02270
      STP=SMS                                                           SUB02280
      SMS=SMS*CMI+CMS*SMI                                               SUB02290
      CMS=CMS*CMI-STP*SMI                                               SUB02300
      IF (K.GT.KMAX) KMAX=K                                             SUB02310
      FM=FM*RM                                                          SUB02320
      DO 12 MA=1,MEXTRA                                                 SUB02330
      MB=MEXTRA-MA+1                                                    SUB02340
12    STM(MB+1)=STM(MB)                                                 SUB02350
      STM(2)=TOTAL                                                      SUB02360
C   SET M TIMER FOR EXTRA M TERMS:                                      SUB02370
      IF (MS.EQ.1) MTIMER=MTIMER+1                                      SUB02380
      IF (JSYM.GT.JMAX) GO TO 9                                         SUB02390
```

```
      IF (K.GT.KEXTRA) MTIMER=0
      IF (M.GE.MLIMIT) GO TO 13
      IF (MTIMER.LE.MEXTRA) GO TO 2
13    IF (MEXTRA.EQ.0) GO TO 9
      TOTAL=0.
      DO 14 MA=1,MEXTRA
14    TOTAL=TOTAL+STM(MA+1)
      RMX=MEXTRA
      TOTAL=TOTAL/RMX
C    END OF M LOOP:  COMPUTE OUTPUT SOLN.
9     MOUT=M-1
      IF (KOUT.EQ.0) KOUT=KMAX-1
      SOLN=TOTAL*EXPON*APP/2.
89    FORMAT ('    M=',I4,',   K=',I4,',   SUBTOTAL=',9E10.3)
88    FORMAT (2X,10E10.3)
      RETURN
      END
C000003
C


      SUBROUTINE BD (M,K,G,H,SCF,B,D,JJMX6)
C
C
C    BD EVALUATES THE FIRST (B) AND SECOND (D) COEFFICIENTS IN THE
C    INVERSION EQUATION, FOR A PARTICULAR SET OF INDEXES M & K.
C    BD MAKES USE OF THE HERMITE POLYNOMIAL ARRAY GENERATED BY
C    SUBROUTINE FIELD AS M & K ADVANCE.
C
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z
      COMMON /SYM/ ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM
      DIMENSION G(IJMX),SCF(JJMX6),H(IIMX)
      PIE=3.141592653589793
      B=0.
      D=0.
      RM=M
      RK=K
      RJMAX=JMAX
      JJMX4=4*JJMX
      DXI=2.*PIE/FCU
200   FORMAT(1X,I10,/)
      IF (JSYM.LE.0) GO TO 4
      IF (M.NE.0) GO TO 2
      S=DXI
      DO 1 J=1,JMAX
      DO 1 I=1,IMAX
      II=I+1
      IJ=IMAX*(J-1)+I
```

```
      DH=H(II)-H(I)                                                     SUB02850
    1 B=B+G(IJ)*S*DH                                                    SUB02860
      B=B*QSYM/2.                                                       SUB02870
      RETURN                                                            SUB02880
    2 DO 3 J=1,JMAX                                                     SUB02890
      JS=J+JJMX4                                                        SUB02900
      S=SCF(JS)/RM                                                      SUB02910
      DO 3 I=1,IMAX                                                     SUB02920
      II=I+1                                                            SUB02930
      IJ=IMAX*(J-1)+I                                                   SUB02940
      DH=H(II)-H(I)                                                     SUB02950
    3 B=B+G(IJ)*S*DH                                                    SUB02960
      B=B*QSYM                                                          SUB02970
      RETURN                                                            SUB02980
    4 IF (M.NE.0) GO TO 6                                               SUB02990
      S=DXI                                                             SUB03000
      DO 5 J=1,JMAX                                                     SUB03010
      DO 5 I=1,IMAX                                                     SUB03020
      II=I+1                                                            SUB03030
      IJ=IMAX*(J-1)+I                                                   SUB03040
      DH=H(II)-H(I)                                                     SUB03050
    5 B=B+G(IJ)*S*DH                                                    SUB03060
      B=B/2.                                                            SUB03070
      RETURN                                                            SUB03080
    6 DO 7 J=1,JMAX                                                     SUB03090
      JS=J+JJMX4                                                        SUB03100
      J2=JS+JJMX                                                        SUB03110
      S=SCF(JS)/RM                                                      SUB03120
      C=SCF(J2)/RM                                                      SUB03130
      DO 7 I=1,IMAX                                                     SUB03140
      II=I+1
      IJ=IMAX*(J-1)+I                                                   SUB03160
      DH=H(II)-H(I)                                                     SUB03170
      B=B+G(IJ)*S*DH                                                    SUB03180
   66 FORMAT ('  BD:',4I5,10F6.2)                                       SUB03190
    7 D=D-G(IJ)*C*DH                                                    SUB03200
      RETURN                                                            SUB03210
      END                                                               SUB03220
C000004                                                                 SUB03230
C                                                                       SUB03240

      SUBROUTINE FIELD2 (RS,SIG,SOL  G,H,SCF,DGN)                       SUB03250
C                                                                       SUB03260
C     FIELD2 COMPUTES THE SAME INVERSION AS SUBROUTINE FIELD, EXCEPT THAT SUB03270
C     THE COEFFICIENTS B AND D ARE COMPUTED INDIVIDUALLY AS USED BY     SUB03280
C     CALLING BD.  DISK STORAGE IS NCT REQUIRED, BUT COMPUTING TIME IS  SUB03290
C     MUCH GREATER.  FIELD2 IS UTILIZED BY S ECIFYING A NEGATIVE MODE ON SUB03300
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C     THE INPUT PARAMETER.                                                  SUB03310
C     FIELD EVALUATES THE VALUE OF THE FIELD FUNCTION AT A PARTICULAR       SUB03320
C     POINT DESIGNATED IN CYLINDRICAL COORDINATES, BY USING THE INVERSION   SUB03330
C     EQUATION OF MALDONADO, ET AL.  FIELD CALLS SUBROUTINES BD & GARRAY.   SUB03340
C                                                                           SUB03350
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z      SUB03360
      COMMON /TAB/ INDEX,KEXTRA,MEXTRA,KLIMIT,MLIMIT,KOUT,MOUT             SUB03370
      COMMON /SYM/ ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM                         SUB03380
      DIMENSION G(IJMX),H(IIMX,5),SCF(JJMX,6)                              SUB03390
C     INITIALIZE THE VALUES:                                                SUB03400
      INDEX=0                                                               SUB03410
      MTIMER=0                                                              SUB03420
      KOUT=0                                                                SUB03430
      MOUT=0                                                                SUB03440
      MMAX=0                                                                SUB03450
      KMAX=0                                                                SUB03460
      TOTAL=0.                                                              SUB03470
      JJMX6=JJMX*6                                                          SUB03480
      IIMX2=(IIMX+1)/2                                                      SUB03490
      AR=ALPHA*RS                                                           SUB03500
      ARG=AR**2                                                             SUB03510
      EXPON=EXP(-ARG)                                                       SUB03520
      PIE=3.14159265358979З                                                 SUB03530
      APP=ALPHA/PIE/PIE                                                     SUB03540
      M=0                                                                   SUB03550
      RM=M                                                                  SUB03560
      RIMAX=IMAX                                                            SUB03570
      DX=2./RIMAX                                                           SUB03580
      RJMAX=JMAX                                                            SUB03590
      DXI=2.*PIE/FCU                                                        SUB03600
C     INITIALIZE THE MODIFIED HERMITE POLYNOMIAL ARRAY:  VECTORS:           SUB03610
C     (1)=H1, (2)=H2, (3)=ALPHA*X(I), (4)=HM+2 STORED, (5)=HM+1 STORED     SUB03620
      DO 1 II=1,IIMX2                                                       SUB03630
      RII=II                                                                SUB03640
      IIM=IIMX-II+1                                                         SUB03650
      H(II,3)=ALPHA*(RII*DX-DX-1.)                                          SUB03660
      H(IIM,3)=-H(II,3)                                                     SUB03670
      H(II,1)=2.*H(II,3)                                                    SUB03680
      H(II,2)=(H(II,3)*H(II,1)-1.)/3.                                       SUB03690
      H(IIM,1)=-H(II,1)                                                     SUB03700
      H(IIM,2)=H(II,2)                                                      SUB03710
      H(II,5)=H(II,2)                                                       SUB03720
      H(IIM,5)=H(IIM,2)                                                     SUB03730
      H(II,4)=H(II,1)                                                       SUB03740
1     H(IIM,4)=H(IIM,1)                                                     SUB03750
      SIGN=1.                                                               SUB03760
      FM=1.                                                                 SUB03770
C     INITIATE THE SIN/COS ARRAY:                                           SUB03780
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      DO 11 J=1,JJMX                                                    SUB03790
      RJM=J-1                                                           SUB03800
      SCF(J,1)=0.                                                       SUB03810
      SCF(J,2)=1.                                                       SUB03820
      SCF(J,3)=SIN(RJM*DXI-PIE)                                         SUB03830
      SCF(J,4)=COS(RJM*DXI-PIE)                                         SUB03840
      SCF(J,5)=0.                                                       SUB03850
11    SCF(J,6)=0.                                                       SUB03860
      MS=0                                                              SUB03870
C   COMMENCE THE M LOOP:                                                SUB03880
2     SIGN=-SIGN                                                        SUB03890
      K=0                                                               SUB03900
      RK=K                                                              SUB03910
      ARM=1.                                                            SUB03920
      IF (M.NE.0) ARM=AR**M                                             SUB03930
      KTIMER=0                                                          SUB03940
      SIGNK=-1.                                                         SUB03950
C   COMPUTE THE K=0 & K=1 ORDERS OF LAGUERRE POLYNOMIAL FOR GIVEN M:    SUB03960
      PM=0.                                                             SUB03970
      P=SQRT(1./FM)                                                     SUB03980
      PP=(RM+1.-ARG)*SQRT(1./FM/(RM+1.))                                SUB03990
C   ADVANCE THE SIN/COS ARRAY FOR NEW M:                                SUB04000
      DO 12 J=1,JJMX                                                    SUB04010
      SCF(J,1)=SCF(J,1)*SCF(J,4)+SCF(J,2)*SCF(J,3)                      SUB04020
12    SCF(J,2)=SCF(J,2)*SCF(J,4)-SCF(J,1)*SCF(J,3)                      SUB04030
      DO 13 J=1,JMAX                                                    SUB04040
      SCF(J,5)=SCF(J+1,1)-SCF(J,1)                                      SUB04050
13    SCF(J,6)=SCF(J+1,2)-SCF(J,2)                                      SUB04060
C   TEST FOR SYMMETRY SKIPS:                                            SUB04070
      IF (MS.EQ.MSYM) MS=0                                              SUB04080
      TOTAL=0.                                                          SUB04090
      MS=MS+1                                                           SUB04100
      IF (MS.NE.1) GO TO 7                                              SUB04110
      RMS=RM*SIG                                                        SUB04120
      CMS=COS(RMS)                                                      SUB04130
      SMS=SIN(RMS)                                                      SUB04140
C   COMMENCE THE K LOOP:                                                SUB04150
3     INDEX=INDEX+1                                                     SUB04160
      SIGNK=-SIGNK                                                      SUB04170
C   CALL THE B & D COEFFICIENTS AND COMPUTE THE M,K SUMMATION TERM:     SUB04180
      CALL BD (M,K,G,H,SCF,B,D,JJMX6)                                   SUB04190
      IF (DGN.LE.-2.) WRITE (6,89) M,K,B,D                              SUB04200
      BRAKET=B                                                          SUB04210
      IF(RM.EQ.0.) GO TO 4                                              SUB04220
      BRAKET=B*CMS+D*SMS                                                SUB04230
4     ADD=SIGNK*BRAKET*P*ARM                                            SUB04240
      TOTAL=TOTAL+ADD                                                   SUB04250
C   ESTABLISH CHECK AS THE RELATIVE SIZE OF THE M,K TERM OF THE SERIES: SUB04260
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      CHECK=ABS(ADD)                                                    SUB04270
      IF (TOTAL.GT.EPS) CHECK=ABS(ADD/TOTAL)                            SUB04280
C     ADVANCE THE K INDEX:                                              SUB04290
      K=K+1                                                             SUB04300
      RK=K                                                              SUB04310
      ORDER=M+2*K+1                                                     SUB04320
C     GENERATE THE NEXT ORDER OF LAGUERRE POLYNOMIAL FOR NEW K:         SUB04330
      PM=P                                                              SUB04340
      P=PP                                                              SUB04350
      PP=P*(ORDER-ARG)-PM*SQRT(RK*(RM+RK))                              SUB04360
      PP=PP/SQRT((RK+1.)*(RM+RK+1.))                                    SUB04370
C     GENERATE THE NEXT ORDER OF THE SET OF HERMITE POLYNOMIALS FOR NEW K:SUB04380
      HA=SQRT(RK*(RK+RM))/ORDER                                         SUB04390
      HB=2.*SQRT((RK+1.)*(RM+RK+1.))/(ORDER+1.)/(ORDER+2.)              SUB04400
      DO 5 II=1,IIMX2                                                   SUB04410
      IIM=IIMX-II+1                                                     SUB04420
      H(II,1)=2.*(H(II,3)*H(II,2)-HA*H(II,1))                           SUB04430
      H(IIM,1)=SIGN*H(II,1)                                             SUB04440
5     H(II,2)=HB*(H(II,3)*H(II,1)-ORDER*H(II,2))                        SUB04450
C     SET K TIMER TO PROVIDE EXTRA K TERMS AFTER CHECK < EPS:           SUB04460
      KTIMER=KTIMER+1                                                   SUB04470
      IF (K.GE.KLIMIT) GO TO 6                                          SUB04480
      IF (MTIMER.LE.MEXTRA) GO TO 2                                     SUB04730
      IF (CHECK.GE.EPS) KTIMER=0                                        SUB04490
      IF (KTIMER.LE.KEXTRA) GO TO 3                                     SUB04500
      GO TO 7                                                           SUB04510
C     END OF K LOOP:  ADVANCE M AND COMPUTE NEW TOTAL:                  SUB04520
6     KOUT=KOUT+1                                                       SUB04530
7     M=M+1                                                             SUB04540
      IF (K.GT.KMAX) KMAX=K                                             SUB04550
      RM=M                                                              SUB04560
      FM=FM*RM                                                          SUB04570
C     REGENERATE THE HERMITE ARRAY FOR NEW M, K=0:                      SUB04580
      DO 8 II=1,IIMX2                                                   SUB04590
      IIM=IIMX-II+1                                                     SUB04600
      H(II,2)=H(II,4)*SQRT(RM)/(RM+1.)                                  SUB04610
      H(II,1)=H(II,5)*(RM+2.)                                           SUB04620
      H(IIM,1)=-SIGN*H(II,1)                                            SUB04630
      H(II,2)=2.*SQRT(RM+1.)*(H(II,3)*H(II,1)-(RM+1.)*H(II,2))          SUB04640
      H(II,2)=H(II,2)/(RM+2.)/(RM+3.)                                   SUB04650
      H(II,4)=H(II,1)                                                   SUB04660
8     H(II,5)=H(II,2)                                                   SUB04670
C     SET M TIMER FOR EXTRA M TERMS:                                    SUB04680
      IF (MS.EQ.1) MTIMER=MTIMER+1                                      SUB04690
      IF (JSYM.GT.JMAX) GO TO 9                                         SUB04700
      IF (K.GT.KEXTRA) MTIMER=0                                         SUB04710
      IF (M.GE.MLIMIT) GO TO 9                                          SUB04720
C     END OF M LOOP:  COMPUTE OUTPUT SOLN.                              SUB04740
```

```
9     MOUT=M-1
      IF (KOUT.EQ.0) KOUT=KMAX-1
      SOLN=TOTAL*EXPON*APP/2.
89    FORMAT ('    M=',I4,',    K=',I4,',    B=',E10.4,',    D=',E10.4)
      RETURN
      END


C000005
C


      SUBROUTINE GARRAY (G,GA,NOF,DGN,NUMB,XO,YO,PHISYM)
C
C    GARRAY FILLS THE DATA ARRAY OVER AN ORTHOGONAL AREA WITH
C    THE REGULAR DATA OBTAINED BY THE METHOD CORRESPONDING TO THE
C    PARTICULAR MODE:
C
C        MODE 1  -  DATA OBTAINED BY SAMPLING A KNOWN FUNCTION SUPPLIED
C                   IN SUBROUTINE FUNCT AND SAMPLED IN SUBROUTINE GOLF.
C
C        MODE 2  -  DATA OBTAINED BY GENERATING A REGULAR ARRAY FROM
C                   IRREGULAR EXPERIMENTAL INPUT DATA READ IN.  CALLS
C                   SUBROUTINE SHEET. (EXPERIMENTAL DATA MAY
C                   BE SIMULATED, SEE 'SHEET')
C
C        MODE 3  -  UTILIZES RAW DATA TAKEN AT THE PROPER INTERVAL,
C                   OR PREVIOUSLY GENERATED, AND READ DIRECTLY INTO THE
C                   GARRAY.  CALLS SUBROUTINE READ.
C
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z
      COMMON /SYM/ ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM
      COMMON /IO/ CMS,IN1,IN2,IN4
      DIMENSION G(IMAX,JMAX),GA(IMAX,JMAX)
      PIE=3.14159265358979З
      HS=SIZE/2.
      IF (MODE.GT.3) MODE=1
      RIMX=IMAX
      RJMX=JMAX
      DELR=SIZE/RIMX
      DELXI=2.*PIE/FCU
      IF (MODE.GT.1) GO TO 2
      DO 1 J=1,JMS
      RJ=J
      XI=(RJ-.5)*DELXI-PIE
      J2=J+2*(JMS-J)
      J3=J+JMAX/2
      J4=J2+JMAX/2
```

```
      DO 1 I=1,IMS
      RI=I
      II=IMAX+1-I
      R=(RI-.5)*DELR-HS
      CALL GOLF (R,XI,GIJ,NOF,DGN,NUMB)
      G(I,J)=GIJ
      IF (ISYM.EQ.2) G(II,J)=GIJ
      IF (ISYM.EQ.2) GO TO 1
      G(II,J3)=GIJ
      IF (JSYM.EQ.0) GO TO 1
      G(I,J2)=GIJ
      G(II,J4)=GIJ
1     CONTINUE
      GO TO 4
2     IF (MODE.GT.2) GO TO 3
      CALL SHEET (G,GA,XO,YO,PHISYM,NOF)
      GO TO 4
3     CALL READ (Z,XO,YO,PHISYM,NOF,IMAX,JMAX,G)
4     IF (DGN.GE.2) WRITE (6,39)
      RETURN
39    FORMAT ('    GARRAY RETURNS')
      END
C000006
C


      SUBROUTINE GOLF (R,XI,GIJ,NOF,DGN,NUMB)
C
C    GOLF COMPUTES THE FUNCTION G(R,XI) FOR A PARTICULAR LINE OF SIGHT
C    FROM A KNOWN FUNCTION CONTAINED IN SUBROUTINE FUNCT.
C
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z
      ZERO=0.
      LMAX=IMAX*3
      RLMAX=LMAX
      DELXP=SIZE/RLMAX
      SXI=SIN(XI)
      CXI=COS(XI)
      DELXS=DELXP*CXI
      DELYS=DELXP*SXI
      XP=DELXP*.5-SIZE/2.
      XS=XP*CXI-R*SXI
      YS=XP*SXI+R*CXI
      GIJ=0.
      DO 1 L=1,LMAX
      RL=L
      CALL FUNCT(XS,YS,F,NOF,DGN,NUMB)
      GIJ=GIJ+F
```

```
      XS=XS+DELXS                                                       SUB00850
1     YS=YS+DELYS                                                       SUB00860
      IF (GIJ.NE.0.) GIJ=GIJ*DELXP*BOX                                  SUB00870
      IF ((SD.EQ.0.).OR.(NUMB.EQ.1)) GO TO 2                            SUB00880
      IF (DGN.GE.3) WRITE (6,28) IX                                     SUB00890
      CALL GAUSS (IX,SD,ZERO,RV)                                        SUB00900
      GIJ=GIJ+RV                                                        SUB00910
2     IF (DGN.GE.3) WRITE (6,29) R,XI,GIJ                               SUB00920
      RETURN                                                            SUB00930
29    FORMAT ('    R=',F8.3,',    XI=',F8.3,',    GIJ=',F8.3)           SUB00940
28    FORMAT ('    GAUSS, IX=',I8)                                      SUB00950
      END                                                               SUB00960
C000007                                                                 SUB00970
C                                                                       SUB00980

      SUBROUTINE FUNCT (XS,YS,F,NOF,DGN,NUMB)                           SUB00990
C                                                                       SUB01000

CP67USERID  1095BOXJ
C
C    FUNCT EVALUATES AS INPUT FUNCTION AT POSITION (X,Y) IN THE TEST    SUB01020
C    SECTION COORDINATE SYSTEM.  NOF IDENTIFIES THE EQUATION USED.      SUB01030
C                                                                       SUB01040
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z   SUB01050
      COMMON /EQPARA/ A,B,C,D,E,P,Q,S,T,U,V,W,RO,RA,NO,NA,N1,N2         SUB01060
      DIMENSION RO(101),RA(101)                                         SUB01070
      AA=A                                                              SUB01080
      BB=B                                                              SUB01090
      CC=C                                                              SUB01100
      DD=D                                                              SUB01110
      EE=E                                                              SUB01120
      PP=P                                                              SUB01130
      IF (NUMB.LE.1) GO TO 50                                           SUB01140
      AA=S                                                              SUB01150
      BB=T                                                              SUB01160
      CC=U                                                              SUB01170
      DD=V                                                              SUB01180
      EE=W                                                              SUB01190
      PP=Q                                                              SUB01200
50    PIE=3.141592653589793                                             SUB01210
      HS=SIZE/2.                                                        SUB01220
      R=SQRT(XS**2+YS**2)/HS                                            SUB01230
      F=0.                                                              SUB01240
      IF (R.GT.1.) GO TO 11                                             SUB01250
      IF (NOF.LE.0) GO TO 11                                            SUB01260
C                                                                       SUB01270
C    1.  AXISYMMETRIC GAUSSIAN:                                         SUB01280
```

```
1     IF (NOF.GT.1) GO TO 2
      F=AA*EXP(-1.*(R*HS/BB)**2)
      GO TO 11
C
C   2.  ADJUSTABLE RECTANGULAR STEP FUNCTION:
2     IF (NOF.GT.2) GO TO 3
      F=PP
      IF ((ABS(XS-DD).LE.BB).AND.(ABS(YS-EE).LE.CC)) F=AA
      GO TO 11
C
C   3.  DISPLACABLE ELLIPTICAL GAUSSIAN:
3     IF (NOF.GT.3) GO TO 4
      F=AA*EXP(-1.*(((XS-DD)/BB)**2+((YS-EE)/CC)**2))
      GO TO 11
C
C   4.  CONSTANT:
4     IF (NOF.GT.4) GO TO 5
      F=AA
      GO TO 11
C
C   5.  ADJUSTABLE AND DISPLACABLE ELLIPTIC RAMP FUNCTION:
5     IF (NOF.GT.5) GO TO 6
      RBC=SQRT(((XS-DD)/BB)**2+((YS-EE)/CC)**2)
      F=0.
      IF (RBC.LT.1.) F=AA*((1.-RBC)**PP)
      GO TO 11
C
C   6.  DISPLACABLE ELLIPTIC STEP FUNCTION:
6     IF (NOF.GT.6) GO TO 7
      RBC=SQRT(((XS-DD)/BB)**2+((YS-EE)/CC)**2)
      F=0.
      IF (RBC.LT.1.) F=AA
      GO TO 11
C
C   7.  CIRCULAR COSINE-SQUARED FUNCTION OF BB MAXIMA:
7     IF (NOF.GT.7) GO TO 8
      F=AA*COS((2.*BB-1.)*PIE*R/2.)**2
      GO TO 11
C
C   8.  NUMERICAL FUNCTION: REQUIRES AN INPUT ARRAY READ IN BY
C       SUBROUTINE FREAD: N FOLLOWED BY N POINT VALUES. (101 MAX)
C       A CONSTANT VALUE AA IS ADDED TO THE FUNCTION.
8     IF (NOF.GT.8) GO TO 9
      IF (NUMB.LE.1) N=NO
      IF (NUMB.GT.1) N=NA
      NM=N-1
      NMM=N-2
      RN=N
```

```
      RI=R*(RN-1.)+1.
      IR=INT(RI)
      RIR=FLOAT(IR)
      DI=RI-RIR
      IF (NUMB.LE.1) F=RO(IR)
      IF (NUMB.GT.1) F=RA(IR)
      IF ((IR.NE.N).AND.(NUMB.LE.1)) F=F+DI*(RO(IR+1)-RO(IR))
      IF ((IR.NE.N).AND.(NUMB.GT.1)) F=F+DI*(RA(IR+1)-RA(IR))
      F=F*AA+B3
      GO TO 11
C
C    9.  SPECIAL FUNCTION:  MAY BE WRITTEN FOR THE OCCASION AND
C         INSERTED IN SUBROUTINE SPFUN
9     IF (NOF.GT.9) GO TO 10
      CALL SPFUN (XS,YS,F)
      GO TO 11
C
C    EQUATIONS NO. 10 AND BEYOND ARE SET TO ZERO.
10    F=0.
C
C
11    IF (DGN.GE.4) WRITE  (6,99) XS,YS,F
99    FORMAT ('    XS=',F8.3,',    YS=',F8.3,',    F=',F8.3)
      RETURN
      END
C000008
C


      SUBROUTINE SPFUN (XS,YS,F)
C
C    SPFUN IS A SPECIAL ROUTINE FOR EQ'N NO. 9.  ANY FUNCTION MAY BE
C    ENTERED.
C
      COMMON /EQPARA/ A,B,C,D,E,P,Q,S,T,U,V,W,RO,RA,NO,NA,N1,N2
      DIMENSION RO(101),RA(101)
      F=0.
      IF ((ABS(XS).LE.B).AND.(ABS(YS).LE.C))  F=A
      RETURN
      END
C000009
C
```

```
      SUBROUTINE SHEET (G,D,XO,YO,PHISYM,NOF)
C
C    SHEET READS IRREGULARLY SPACED VALUES OF THE LINE INTEGRAL, AS
C    OBTAINED FROM HOLOGRAPHIC INTERFEROGRAMS.  THE INTEGRAL LINES MAY BE
C    DEFINED EITHER BY GRID INTERCEPT POSITIONS, OR BY ANGLE AND RADIUS
C    ABOUT THE CENTER OF THE LABORATORY COORDINATE SYSTEM CENTER.  LINES
C    MUST BE ENTERED IN CONSECUTIVE ORDER FROM LOWEST (NEG.) TO HIGHEST
C    (POS.) RADIUS.  DATA MAY BE SIMULATED BY SPECIFYING NCODE=1,
C    FOLLOWED BY APERATURE POSITIONS FOR A FUNCTION NUMBER IN 'SUBFUNCT'.
C
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z
      COMMON /SYM/ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM
      COMMON /IO/ CMS,IN1,IN2,IN4
      DIMENSION G(IMAX,JMAX),D(IMAX,JMAX),XI(303),RR(303)
      DIMENSION XG(303),XD(303),YG(303),YD(303),XY(303)
      NAR=303
      PIE=3.141592653589793
      MPIE=-PIE
      TPIE=2.*PIE
      MPIT=MPIE/2.
      PIET=PIE/2.
C    ZERO THE ARRAYS:
      DO 1 J=1,JMAX
      DO 1 I=1,IMAX
      G(I,J)=0.
    1 D(I,J)=0.
      DO 2 I=1,NAR
      XG(I)=0.
      XO(I)=0.
      YG(I)=0.
      YD(I)=0.
      XY(I)=0.
      XI(I)=0.
    2 RR(I)=0.
C    READ THE BASIC DATA:
      IF (CMS.EQ.1.) REWIND 1
      READ (IN1,59) NOF,NCODE
      READ (IN1,58) Z,XO,YO,PHISYM,XMX,XMN,YMX,YMN
      READ (IN1,59) JM
      RIMX=IMAX
      DR=SIZE/RIMX
      R=(-DR-SIZE)/2.
      RZO=SQRT(XO**2+YO**2)
      GAM=ATANM(YO,XO)
      TP=3-ISYM
      BT=JSYM
      DAN=PIE*TP/BT
      HS=SIZE/2.
```

```
      MXY=1
      IF((XMX.NE.O.).OR.(XMN.NE.O.).OR.(YMX.NE.O.).OR.(YMN.NE.O.))MXY=2
      IF (MXY.EQ.1) GO TO 3
      XMX=XO+HS
      YMX=YO+HS
      XMN=XO-HS
      YMN=YO-HS
C   COMMENCE THE READ AND FILL LOOP:
3     DO 12 J=1,JM
      READ (IN1,59)IM
      MN=0
      XH=0.
      YH=0.
C   READ THE LINES, DETERMINE CODE, CALCULATE RADIUS & ANGLE FOR CODE 1:
      DO 5 I=1,IM
      IF(NCODE.LE.O)READ(IN1,58) XD(I),YD(I),XG(I),YG(I),D(I,J),RR(I),
     1XI(I),XY(I)
      IF(NCODE.GE.1)CALL SIM(XD(I),YD(I),XG(I),YG(I),RR(I),XI(I),
     1XY(I),XO,YO,PHISYM,XMX,XMN,YMX,YMN,NOF,I,IM)
      IF (XY(I).EQ.3.) GO TO 5
      IF((XD(I).NE.O.).OR.(YD(I).NE.O.)) XY(I)=1.
      IF((XG(I).NE.O.).OR.(YG(I).NE.O.)) XY(I)=1.
      IF(((RR(I).NE.O.).OR.(XI(I).NE.O.)).AND.(XY(I).EQ.O.)) XY(I)=2.
      IF((XY(I).EQ.O.).AND.(D(I,J).NE.O.)) XY(I)=2.
      IF (XY(I).NE.1.) GO TO 4
      DEN=SQRT((XG(I)-XD(I))**2+(YG(I)-YD(I))**2)
      IF (DEN.EQ.O.) XY(I)=4.
      IF (XY(I).EQ.4.) GO TO 4
      RR(I)=((XO-XD(I))*(YG(I)-YD(I))-(XG(I)-XD(I))*(YO-YD(I)))/DEN
      XI(I)=ATANM((YG(I)-YD(I)),(XG(I)-XD(I)))
      XIM=XI(I)
4     IF (XY(I).EQ.2.) XIM=XI(I)
      XIN=XIM
      IF(XY(I).EQ.2.) RR(I)=RR(I)+RZO*SIN(GAM-XI(I))
5     CONTINUE
C   COMPUTE MAX AND MIN ANGLE INDEXES FOR APERATURE POSITION LOCATION:
      DO 6 I=1,IM
      IF((XY(I).NE.1.).OR.(XY(I).NE.2.)) GO TO 6
      IF (XI(I).GT.XIM) XIM=XI(I)
      IF (XI(I).GT.XIM) IMT=I
      IF (XI(I).LT.XIN) XIN=XI(I)
      IF (XI(I).LE.XIN) INT=I
6     CONTINUE
C   DETERMINE APERATURE LOCATION:
      LPR=0
      XID=XI(IMT)-XI(INT)
      IF(ABS(XID).LT..00001) LPR=1
      XIH=(XI(IMT)+XI(INT))/2.
```

```
      RRH=10000.
      XH=RRH*COS(XIH)
      YH=RRH*SIN(XIH)
      IF (LPR.EQ.1) GO TO 7
      YTX=-RR(IMT)*SIN(XI(IMT))-YO
      YTN=-RR(INT)*SIN(XI(INT))-YO
      XTX=RR(IMT)*COS(XI(IMT))-XO
      XTN=RR(INT)*COS(XI(INT))-XO
      UA=TAN(XI(IMT))
      UC=TAN(XI(INT))
      UB=YTX-UA*XTX
      UD=YTN-UC*XTN
      XH=(UD-UB)/(UA-UC)
      YH=XH*UA+UB
      RRH=SQRT((XH-XO)**2+(YH-YO)**2)
      XIH=ATANM((YH-YO),(XH-XO))
7     CONTINUE
C   FILL THE ANGLE AND RADIUS FOR ANY CODE 3 OR 4 LINES:
      DO 9 I=1,IM
      IF(XY(I).NE.3.) GO TO 8
      BAS=SQRT(RRH**2-RR(I)**2)
      XI(I)=XIH-ATANM(RR(I),BAS)
      GO TO 9
8     XI(I)= ATANM((YH-YD(I)),(XH-XD(I)))
      RR(I)=RRH*SIN(XI(I)-XIH)
9     CONTINUE
C   ANGLES AND RADII ARE NOW FILLED FOR ALL POINTS IN THIS LINE.
C   VACATE THE SET OF VECTORS TO BE USED AS TEMPORARY STORAGE:
      DO 10 I=1,IM
      XD(I)=0.
      YD(I)=0.
      XG(I)=0.
      YG(I)=RR(I)
      XY(I)=D(I,J)
      RR(I)=0.
      D(I,J)=0.
10    XI(I)=0.
C   CONVERT THE LINE TO REGULAR RADII USING INTERPOLATION:
      RR(1)=R+DR
      CALL SPLINE(YG,XY,IM,RR(1),D(1,J))
      DO 11 I=2,IMAX
      RI=I
      RR(I)=R+DR*RI
11    CALL SPLINN(YG,XY,IM,RR(I),D(I,J))
C   GENERATE THE VECTOR OF ANGLES FOR THIS COLUMN AND STORE IN G ARRAY:
      DO 12 I=1,IMAX
      BAS=SQRT(RRH**2-RR(I)**2)
      G(I,J)=XIH-ATANM(RR(I),BAS)
```

```
      YG(I)=0.                                                  SUB03610
      D(I,J)=XY(I)                                              SUB03620
   12 XY(I)=0.                                                  SUB03630
C     COLUMNS ARE NOW ALL REGULARLY FILLED.                     SUB03640
C     NEXT,INTERPOLATE EACH ROW REGULARLY OVER THE ANGLES.      SUB03650
      DO 23 I=1,IMAX                                            SUB03660
C     EXPAND THE DATA TO 2 SETS TO ESTABLISH SMOOTH INTERPOLATION. SUB03670
      JM3=3*JM                                                  SUB03680
      II=IMAX+1-I                                               SUB03690
      IF (JSYM.NE.0) GO TO 14                                   SUB03700
      DO 13 J=1,JMS                                             SUB03710
      J2=J+JMS                                                  SUB03720
      J3=J2+JMS                                                 SUB03730
      XD(J)=D(I,J)                                              SUB03740
      XD(J2)=D(II,J)                                            SUB03750
      XD(J3)=D(I,J)                                             SUB03760
      XG(J)=G(I,J)-TPIE-PHISYM                                  SUB03770
      XG(J2)=G(II,J)-PIE-PHISYM                                 SUB03780
   13 XG(J3)=G(I,J)-PHISYM                                      SUB03790
      GO TO 16                                                  SUB03800
   14 DO 15 J=1,JMS                                             SUB03810
      J1=JMS+1-J                                                SUB03820
      J2=JMS+J                                                  SUB03830
      J3=JM3+1-J                                                SUB03840
      XD(J1)=D(I,J)                                             SUB03850
      XD(J2)=D(II,J)                                            SUB03860
      XD(J3)=D(II,J)                                            SUB03870
      XG(J1)=G(I,J)-2.*(G(I,J)-PHISYM)-PIE-PHISYM               SUB03880
      XG(J2)=G(II,J)-PIE-PHISYM                                 SUB03890
   15 XG(J3)=G(II,J)+2.*(DAN+PHISYM-G(II,J))-PIE-PHISYM         SUB03900
   16 CONTINUE                                                  SUB03910
      JM2=2*JMS                                                 SUB03920
      JP=JMS/2                                                  SUB03930
      DO 17 J=1,JM2                                             SUB03940
      XD(J)=XD(J+JP)                                            SUB03950
   17 XG(J)=XG(J+JP)                                            SUB03960
      JJS=JM2+1                                                 SUB03970
      DO 18 J=JJS,JM3                                           SUB03980
      XD(J)=0.                                                  SUB03990
   18 XG(J)=0.                                                  SUB04000
C     FIND THE SMALLEST ANGLE                                   SUB04010
      XY(1)=1.                                                  SUB04020
      SA=XG(1)                                                  SUB04030
      DO 19 J=1,JM2                                             SUB04040
      IF (XG(J).GE.SA) GO TO 19                                 SUB04050
      SA=XG(J)                                                  SUB04060
      XY(1)=J                                                   SUB04070
   19 CONTINUE                                                  SUB04080
```

```
C     FIND THA MAX ANGLE IN THE ROW:
      XY(JM2)=JM2
      SB=XG(JM2)
      DO 20 J=1,JM2
      IF (XG(J).LE.SB) GO TO 20
      SB=XG(J)
      XY(JM2)=J
20    CONTINUE
C     DETERMINE THE ORDER OF INCREASING ANGLE IN THE ROW
      SB=XG(JM2)
      JJ=2
21    JSA=XY(JJ-1)
      SA=XG(JJ-1)
      JTS=0
      DO 22 J=1,JM2
      IF (XG(J).LE.SA) GO TO 22
      IF (XG(J).GT.SB) GO TO 22
      SB=XG(J)
      XY(JJ)=J
      JTS=1
22    CONTINUE
      IF (JTS.EQ.0) JM2=JJ
      JJ=JJ+1
      IF (JJ.LE.JM2) GO TO 21
      DO 23 J=1,JM2
      JX=XY(J)
23    YD(J)=XD(JX)
C     INTERPOLATE:
      DXI=2.*PIE/FCU
      XI(J)=DXI/2.-PIE-PHISYM
      CALL SPLINE (XG,YD,JM2,XI(J),G(I,J))
      DO 24 J=2,JMS
      XI(J)=XI(J-1)+DXI
24    CALL SPLINN (XG,YD,JM2,XI(J),G(I,J))
      DO 25 J=1,JMS
      XIJ=XI(J)
      XU=XMX
      IF ((XIJ.GE.O.).AND.(XIJ.LT.PIE)) XU=XMN
      YU=YMN
      IF ((XIJ.GE.MPIT).AND.(XIJ.LT.PIT)) YU=YMX
      XL=XMN
      IF ((XIJ.GE.O.).AND.(XIJ.LT.PIE)) XL=XMX
      YL=YMX
      IF ((XIJ.GE.MPIT).AND.(XIJ.LT.PIT)) YL=YMN
      SXIJ=SIN(XIJ)
      CXIJ=COS(XIJ)
      RMN=(XO-XL)*SXIJ-(YO-YL)*CXIJ
      RMX=(XO-XU)*SXIJ-(YO-YU)*CXIJ
```

```
      DO 25 I=1,IMAX                                              SUB04570
      IF (RR(I).LT.RMN) G(I,J)=0.                                 SUB04580
      IF (RR(I).GT.RMX) G(I,J)=0.                                 SUB04590
25    CONTINUE                                                    SUB04600
C   EXPAND SYMMETRY SECTOR INTO AN ORTHOGONAL INTERVAL.           SUB04610
      IF (ISYM.EQ.2) GO TO 27                                     SUB04620
      DO 26 J=1,JMS                                               SUB04630
      J2=JMAX/2+1-J                                               SUB04640
      J3=JMAX/2+J                                                 SUB04650
      J4=JMAX+1-J                                                 SUB04660
      DO 26 I=1,IMAX                                              SUB04670
      II=IMAX+1-I                                                 SUB04680
      G(I,J2)=G(I,J)                                              SUB04690
      G(II,J3)=G(I,J)                                             SUB04700
26    G(II,J4)=G(I,J)                                             SUB04710
      RETURN                                                      SUB04720
C   FOR EVEN SYMMETRY, AVERAGE THE GARRAY COLUMNS.                SUB04730
27    IMS=(2*IMAX+1)/2                                            SUB04740
      DO 28 J=1,JMAX                                              SUB04750
      DO 28 I=1,IMS                                               SUB04760
      II=IMAX+1-I
      GST=(G(I,J)+G(II,J))/2.                                     SUB04780
      G(I,J)=GST                                                  SUB04790
28    G(II,J)=GST                                                 SUB04800
      RETURN                                                      SUB04810
59    FORMAT (5I5)                                                SUB04820
58    FORMAT (10F7.3)                                             SUB04830
      END                                                         SUB04840
C000010                                                           SUB04850
C                                                                 SUB04860


      FUNCTION ATANM(Y,X)                                         SUB04870
C                                                                 SUB04880
C   COMPUTES THE ARCTAN OF Y/X BETWEEN -P1 AND +P1.               SUB04890
C                                                                 SUB04900
      PIE=3.141592653589793                                       SUB04910
      PI2=PIE/2.                                                  SUB04920
      ATANM=SIGN(PI2,Y)                                           SUB04930
      IF(X.NE.0.) ATANM=ATAN(Y/X)                                 SUB04940
      IF(X.GE.0.) RETURN                                          SUB04950
      IF(Y.GE.0.) ATANM=PIE+ATANM                                 SUB04960
      IF(Y.LT.0.) ATANM=-PIE+ATANM                                SUB04970
      RETURN                                                      SUB04980
      END                                                         SUB04990
C000011                                                           SUB05000
C                                                                 SUB05010
```

```
      SUBROUTINE SIM (XD,YD,XG,YG,D,R,XI,XY,XO,YO,PS,XM,XN,YM,YN,I,IM,    SUB05020
     1DG,NF)                                                              SUB05030
C    SIM SIMULATES THE FRINGE NUMBER DATA ONE WOULD OBTAIN FROM THE       SUB05040
C    HOLOGRAPHIC INTERFEROGRAM PROCESS FOR A KNOWN FUNCTION AS            SUB05050
C    CONTAINED IN SUBROUTINE FUNCT.  THE GRID BOX DIMENSIONS MUST         SUB05060
C    EXCEED THE INVERSION CIRCLE SIZE, AND APERATURE POINTS SPECIFIED     SUB05070
C    MUST FALL BETWEEN XI=-40 DEGREES, AND XI=+130 DEGREES.               SUB05080
C                                                                         SUB05090
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALF,SIZ,EPS,MOD,BOX,SD,IX,Z         SUB05100
      COMMON /IO/ CMS,IN1,IN2,IN4                                         SUB05110
      READ (IN1,29) XH,YH                                                 SUB05120
      ZER=0.                                                              SUB05130
      RIM=IM                                                              SUB05140
      RI=I                                                                SUB05150
      DX=(XM-XN)/(RIM-1.)                                                 SUB05160
      DY=(YM-YN)/(RIM-1.)                                                 SUB05170
      X1=XM-(RIM-1.)*DX                                                   SUB05180
      Y1=YM-(RIM-1.)*DY                                                   SUB05190
      XI1=ATANM (YH-Y1,XH-X1)-PS                                          SUB05200
      RRH=SQRT((XH-XO)**2+(YH-YO)**2)                                     SUB05210
      XIO=ATANM(YH-YO,XH-XO)-PS                                           SUB05220
      R1=RRH*SIN(XI1-XIO)                                                 SUB05230
      IF ((I.GT.1).AND.(I.LT.IM)) GO TO 1                                 SUB05240
      IF (ABS(R1).LT.SIZ/2.) R1=SIGN(SIZ/2.,R1)                           SUB05250
      XY=3.                                                               SUB05260
      GO TO 2                                                             SUB05270
1     CALL GOLF (R,XI,D,XR,ZER,ZER)                                       SUB05280
      XD=XN                                                               SUB05290
      YD=YN                                                               SUB05300
      IF (XH.NE.X1) YD=Y1-(X1-XN)*(YH-Y1)/(XH-X1)                         SUB05310
      IF (YS.GE.YN) GO TO 2                                               SUB05320
      YD=YN                                                               SUB05330
      IF (YH.NE.Y1) XD=X1-(Y1-YN)*(XH-X1)/(YH-Y1)                         SUB05340
2     RETURN                                                              SUB05350
29    FORMAT (10F7.3)                                                     SUB05360
      END                                                                 SUB05370
                                                                          SUB05380
C000012                                                                   SUB00010
C                                                                         SUB00020

      SUBROUTINE FREAD (NO,RO,NF,ZZ)                                      SUB00030
C                                                                         SUB00040
C    FREAD READS THE NUMERIC ARRAY WHICH IS USED FOR EQUATION 8 OF        SUB00050
C    SUBROUTINE FUNCT.  FIRST CARD IS NUMBER OF POINTS (N.GE.1),          SUB00060
C    FOLLOWED BY ONE POINT PER CARD.                                      SUB00070
C                                                                         SUB00080
      DIMENSION RO(101)                                                   SUB00090
```

```
      READ (NF,89) NO,ZZ                                                SUB00100
      WRITE(6,90) NO,ZZ
      DO  10  I=1,NO
      READ(NF,88)  RO(I)
      WRITE(6,88)  RO(I)
   10 CONTINUE
89    FORMAT (I5,F9.3)                                                  SUB00120
   88 FORMAT(F8.5)
   90 FORMAT(1X,I5,F9.3)
      RETURN                                                            SUB00140
      END                                                               SUB00150
C000013                                                                 SUB00160
C                                                                       SUB00170

      SUBROUTINE GPRINT (G,NUMB)                                        SUB00180
C                                                                       SUB00190
C   GPRINT PRINTS THE DATA ARRAY 'G'  WHICH WAS INPUT TO                SUB00200
C   THE PROGRAM IN SUBROUTINE GARRAY.                                   SUB00210
C                                                                       SUB00220
      COMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z   SUB00230
      DIMENSION G(IJMX)                                                 SUB00240
      DIMENSION X(15)                                                   SUB00250
      DATA HYP,VERT/1H-,1H|/                                            SUB00260
      IF (NUMB.EQ.1) WRITE (6,99) MODE,Z                                SUB00270
      IF (NUMB.EQ.2) WRITE (6,92) Z                                     SUB00280
      JM2=JMAX/2                                                        SUB00290
      RIMAX=IMAX                                                        SUB00300
      RJMAX=JMAX                                                        SUB00310
      DX=SIZE/RIMAX                                                     SUB00320
      DXI=360./RJMAX                                                    SUB00330
C   INTRVL SETS THE NUMBER OF TERMS PRINTED PER LINE. IF IT IS ALTERED, SUB00340
C   ONE MUST ALSO REDIMENSION X AND ALTER FORMATS 98, 97, AND 95.       SUB00350
      INTRVL=15                                                         SUB00360
      IB=1                                                              SUB00370
      IT=IB+INTRVL-1                                                    SUB00380
1     IF (IT.GT.IMAX) IT=IMAX                                           SUB00390
      IBT=IT-IB+1                                                       SUB00400
      WRITE (6,98) (II,II=IB,IT)                                        SUB00410
      DO 2 I=1,IBT                                                      SUB00420
      RI=IB-1+I                                                         SUB00430
2     X(I)=-SIZE/2.+(RI-.5)*DX                                          SUB00440
      LM=7*IBT+1                                                        SUB00450
      WRITE (6,97) (X(I),I=1,IBT)                                       SUB00460
      WRITE (6,96) (HYP,L=1,LM),VERT                                    SUB00470
      JMH=JM2+1                                                         SUB00480
      DO 3 J=JMH,JMAX                                                   SUB00490
      RJ=J                                                              SUB00500
```

```
      XI=-180.+DXI*(RJ-.5)                                              SUB00510
      IGB=(J-1)*IMAX+IB                                                 SUB00520
      IGT=IGB-IB+IT                                                     SUB00530
3     WRITE (6,95) J,XI,(G(L),L=IGB,IGT)
      WRITE (6,94) (HYP,L=1,LM),VERT                                    SUB00550
      IB=IB+INTRVL                                                      SUB00560
      ITOLD=IT                                                          SUB00570
      IT=IT+INTRVL                                                      SUB00580
      IF (ITOLD.LT.IMAX) GO TO 1                                        SUB00590
      WRITE (6,93)                                                      SUB00600
99    FORMAT (1H1//'    THE ARRAY OF INPUT DATA (G), OBTAINED BY GARRAY, SUB00610
     1MODE ',I1,', FOR Z='F7.3,' CM:')                                  SUB00620
98    FORMAT (///11X,'I= ',15I7)                                        SUB00630
97    FORMAT (11X,'X=   ',15F7.3)                                       SUB00640
96    FORMAT ('     J=        XI= |',115A1)                             SUB00650
95    FORMAT (2X,I3,F9.2,'|',15F7.3)                                    SUB00660
94    FORMAT (14X,'|',115A1)                                            SUB00670
93    FORMAT (///5X)                                                    SUB00680
92    FORMAT (1H1//'    THE ADD-ON FUNCTION GARRAY FOR Z=',F7.3,' CM:') SUB00690
      RETURN                                                            SUB00700
      END                                                               SUB00710
C000014                                                                 SUB00720
C                                                                       SUB00730


      SUBROUTINE GPUNCH (Z,XO,YO,PHS,NOF,IMX,JMX,G)                     SUB00740
C                                                                       SUB00750
C    GPUNCH PUNCHES OUT THE FIRST NON-SYMME RIC PORTION OF GARRAY       SUB00760
C    (OR WRITES IT ON FILE 7 IN CMS VERSION)                            SUB00770
C                                                                       SUB00780
      COMMON /SYM/ ISM,JSM,MSM,FCU,IMS,JMS,QSM                          SUB00790
      DIMENSION G(IMX,JMX)                                              SUB00800
      WRITE (7,39) NOF,IMX,JMX,ISM,JSM,IMS,JMS                          SUB00810
      WRITE (7,38) ((G(I,J),I=1,IMS),J=1,JMS)                           SUB00820
39    FORMAT(10I5)                                                      SUB00830
38    FORMAT(10F7.3)                                                    SUB00840
      RETURN                                                            SUB00850
      END                                                               SUB00860
C000015                                                                 SUB00870
C                                                                       SUB00880


      SUBROUTINE READ (Z,XO,YO,PHISYM,NOF,IMAX,JMAX,G)                  SUB00890
C                                                                       SUB00900
C    READS THE NON-SYMME   C PORTION OF THE GARRAY AND EXPANDS IT TO AN SUB00910
C    ORTHOGONAL SET. NOT  . INSURE SUFFICIENT DIMENSIONS IN MAIN PROGRAM. SUB00920
C                                                                       SUB00930
      COMMON /SYM/ ISYM,JSYM,MSYM,FCU,IMS,JMS,QSYM                      SUB00940
```

```
      COMMON /IO/ CMS,IN1,IN2,IN4                                       SUB00950
      DIMENSION G(IMAX,JMAX)                                            SUB00960
      READ (IN1,39) NOF,IMAX,JMAX,ISYM,JSYM,IMS,JMS                     SUB00970
      READ(IN1,40) Z,XO,YO,PHISYM
      DO 10 J=1,JMS
   10 READ(IN1,33) (G(I,J),I=1,IMS)
      WRITE(6,37) NOF,Z,XO,YO,PHISYM,IMAX,JMAX,JSYM                     SUB01000
      RJMX=JMAX                                                         SUB01010
      MSYM=JSYM                                                         SUB01020
      IF ((MSYM.EQ.0).OR.(MSYM.GT.JMAX)) MSYM=1                         SUB01030
      FCU=ISYM*JSYM*JMAX                                                SUB01040
      IF (JSYM.GT.JMAX) FCU=JMAX                                        SUB01050
      QSYM=FCU/RJMX                                                     SUB01060
      DO 4 J=1,JMS                                                      SUB01070
      IF(ISYM.EQ.1) GO TO 2                                             SUB01080
      DO 1 I=1,IMS                                                      SUB01090
      II=IMAX+1-I                                                       SUB01100
1     G(II,J)=G(I,J)                                                    SUB01110
      GO TO 4                                                           SUB01120
2     J2=JMAX/2+1-J                                                     SUB01130
      J3=JMAX/2+J                                                       SUB01140
      J4=JMAX+1-J                                                       SUB01150
      DO 3 I=1,IMAX                                                     SUB01160
      II=IMAX+1-I                                                       SUB01170
      G(I,J2)=G(I,J)                                                    SUB01180
      G(II,J3)=G(I,J)                                                   SUB01190
3     G(II,J4)=G(I,J)                                                   SUB01200
4     CONTINUE                                                          SUB01210
39     FORMAT(10I5)                                                     SUB01220
   40 FORMAT(4F7.3)
   38 FORMAT(10F7.3)
37    FORMAT(///'  MODE 3 READS GARRAY DIRECTLY:    NOF='I4/'     Z='F7.3SUB01240
     1,',    XO=',F7.3,',    YO=',F7.3,',    PHISYM=',F7.3/'    IMAX=',I4,SUB01250
     2',   JMAX=',I4,',    JSYM=',I4///)                                SUB01260
      RETURN                                                            SUB01270
      END                                                               SUB01280
C000016                                                                 SUB01290
C                                                                       SUB01300

      SUBROUTINE MAP (IM,JM,A,N,Z,BAND)                                 SUB01310
C                                                                       SUB01320
C    MAP CALLS SUBROUTINE MIMPII AND PLOTS A CONTOUR MAP OF THE ARRAY   SUB01330
C                                                                       SUB01340
      DIMENSION A(IM,JM),T(24)                                          SUB01350
      DATA BL/1H /                                                      SUB01360
      DO 1 I=1,24                                                       SUB01370
1     T(I)=BL                                                           SUB01380
```

```
      ICON=1                                                            SUB01390
      IF(BAND.LT.O.) ICON=0                                             SUB01400
      IF(BAND.LT.O.) BAND=-BAND                                         SUB01410
      AMIN=0.                                                           SUB01420
      IJT=0                                                             SUB01430
      AZ=1.                                                             SUB01440
      BZ=0.                                                             SUB01450
      WRITE(6,49) N,Z                                                   SUB01460
      CALL MTMPII (A,IM,JM,T,BAND,AZ,BZ,AMIN,IJT,ICON)                  SUB01470
49    FORMAT (1H1//'  THE FUNCTION SURFACE, TEST NO.'I3,'  Z='F5.3//)   SUB01480
      RETURN                                                            SUB01490
      END                                                               SUB01500
C000017                                                                 SUB01510
C                                                                       SUB01520

      SUBROUTINE GPLOT (G,GA,JMS)                                       SUB01530
C                                                                       SUB01540
C    GPLCT PRINTS A ROUGH PLOT OF THE LINE INTEGRAL FUNCTIONS IN GARRAY. SUB01550
C                                                                       SUB01560
      CCMMON IMAX,JMAX,IIMX,JJMX,IJMX,ALPHA,SIZE,EPS,MODE,BOX,SD,IX,Z   SUB01570
      COMMON /TAB/ INDEX(7),JSYM,ISYM                                   SUB01580
      COMMON /TAB2/ IPT,KPT,LPT,MPT,REST(5)                             SUB01590
      DIMENSION G(IMAX,JMAX),GA(IMAX,JMAX),ROW(101)                     SUB01600
      DIMENSION A(201),B(101),C(201),D(101)                             SUB01610
      JM=101                                                            SUB01620
      DATA BL,PL,ST,DH,EX/1H ,1H+,1H*,1H-,1HX/                          SUB01630
      JMS2=JMAX/2+1                                                     SUB01640
      IF(ISYM.EQ.2)JMS2=1                                               SUB01650
      JMS3=JMS2+JMS-1                                                   SUB01660
      DO 8 J=JMS2,JMS3                                                  SUB01670
      WRITE(6,67) (ST,I=1,120)                                          SUB01680
      DO 1 I=1,IMAX                                                     SUB01690
      A(I)=G(I,J)                                                       SUB01700
1     C(I)=GA(I,J)                                                      SUB01710
      AS=.5                                                             SUB01720
      BS=.0                                                             SUB01730
      CALL INTERP (A,IMAX,AS,B,JM,BS)                                   SUB01740
      CALL INTERP (C,IMAX,AS,D,JM,BS)                                   SUB01750
      WRITE (6,69) J                                                    SUB01760
      BIG=0.                                                            SUB01770
      SMALL=0.                                                          SUB01780
      DO 2 I=1,IMAX                                                     SUB01790
      IF(A(I).GT.BIG) BIG=A(I)                                          SUB01800
      IF(C(I).GT.BIG) BIG=C(I)                                          SUB01810
      IF(A(I).LT.SMALL) SMALL=A(I)                                      SUB01820
2     IF(C(I).LT.SMALL) SMALL=C(I)                                      SUB01830
      RANGE=BIG-SMALL                                                   SUB01840
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      RINK=RANGE/80.                                                    SUB01850
      TOP=BIG+RINK                                                      SUB01860
      CEN=BIG                                                           SUB01870
      BOT=BIG-RINK                                                      SUB01880
      KC=0                                                              SUB01890
      DO 7 K=1,41                                                       SUB01900
      IC=0                                                              SUB01910
      DO 6 I=1,101                                                      SUB01920
      ROW(I)=BL                                                         SUB01930
      IF((I.EQ.1).OR.(I.EQ.51).OR.(I.EQ.101))ROW(I)=PL                  SUB01940
      IF((K.EQ.1).OR.(K.EQ.41)) ROW(I)=PL                               SUB01950
      IF((TOP.GE.0.).AND.(BOT.LE.0.)) ROW(I)=DH                         SUB01960
      IF(IC.EQ.5) GO TO 3                                               SUB01970
      GO TO 4                                                           SUB01980
3     IC=0                                                              SUB01990
      IF(KC.EQ.10) ROW(I)=PL                                            SUB02000
4     IF(KPT.LE.2) GO TO 5                                              SUB02010
      IF((D(I).LE.TOP).AND.(D(I).GE.BOT)) ROW(I)=ST                     SUB02020
5     IF((B(I).LE.TOP).AND.(B(I).GE.BOT)) ROW(I)=EX                     SUB02030
6     IC=IC+1                                                           SUB02040
      IF(KC.EQ.5) KC=0                                                  SUB02050
      IF(KC.NE.0) WRITE (6,65) (ROW(I),I=1,101)                         SUB02060
      IF(KC.EQ.0) WRITE (6,68) CEN,(ROW(I),I=1,101)                     SUB02070
      TOP = TOP-2.*RINK                                                 SUB02080
      CEN=CEN-2.*RINK                                                   SUB02090
      BOT=BOT-2.*RINK                                                   SUB02100
7     KC=KC+1                                                           SUB02110
8     WRITE (6,66) (ST,I=1,120)                                         SUB02120
69    FORMAT (//'     J=',I3///)                                        SUB02130
68    FORMAT (1X,F8.3,1X,101A1)                                         SUB02140
67    FORMAT (1H1,//121A1//)                                            SUB02150
66    FORMAT (///121A1///)                                              SUB02160
65    FORMAT (10X,101A1)                                                SUB02170
      RETURN                                                            SUB02180
      END                                                               SUB02190
C000018                                                                 SUB02200
C                                                                       SUB02210
      SUBROUTINE INTERP (A,IM,AS,B,JM,BS)                               SUB02220
C                                                                       SUB02230
C    INTERP CONVERTS A REGULAR VECTOR A OF IM POINTS TO A REGULAR VECTOR SUB02240
C    B OF JM POINTS.  OS=.5 FOR A VECTOR WITH POINTS DEFINED IN THE     SUB02250
C    CENTER OF THE INTERVAL, AS AND BS ARE THE % OF AN INTERVAL FROM THE SUB02260
C    EDGE OF THE FIELD TO THE FIRST POINT (.0 OR .5 FOR EDGE OR CENTER  SUB02270
C    DEFINED POINTS)                                                    SUB02280
C                                                                       SUB02290
      DIMENSION A(IM),B(JM)                                             SUB02300
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```
      RIM=IM                                                            SUB02310
      RJM=JM                                                            SUB02320
      RAT=(RIM-1.+2.*AS)/(RJM-1.+2.*BS)                                 SUB02330
      DO 2 I=1,JM                                                       SUB02340
      BI=I                                                              SUB02350
      AI=RAT*(BI+BS)-AS                                                 SUB02360
      IA=AI                                                             SUB02370
      F=AI-FLOAT(IA)                                                    SUB02380
      IF((IA.EQ.0).OR.(IA.EQ.JM)) GO TO 1                               SUB02390
      B(I)=A(IA)+F*(A(IA+1)-A(IA))                                      SUB02400
      GO TO 2                                                           SUB02410
1     IF(IA.EQ.0) B(I)=A(1)*(F-AS)/(1.-AS)                              SUB02420
      IF(IA.EQ.JM) B(I)=A(JM)*F/(1.-AS)                                 SUB02430
2     CONTINUE                                                          SUB02440
      RETURN                                                            SUB02450
      END                                                               SUB02460
                                                                        SUB02470
C000019
C     ------------------------------------------------------------------SPL00010
C                                                                       SPL00020
C        SUBROUTINE SPLINE                                              SPL00030
C                                                                       SPL00040
C        PURPOSE                                                        SPL00050
C           PROVIDES INTERPOLATED VALUE USING "CUBIC SPLINE FITTING"    SPL00060
C                                                                       SPL00070
C        USAGE                                                          SPL00080
C           FIRST CALL TO SUBROUTINE:                                   SPL00090
C           CALL SPLINE(X,Y,M,XINT,YINT)                                SPL00100
C                                                                       SPL00110
C           SUBSEQUENT CALLS:                                           SPL00120
C           CALL SPLINN(X,Y,M,XINT,YINT)                                SPL00130
C                                                                       SPL00140
C        DESCRIPTION OF PARAMETERS                                      SPL00150
C           X:     MONOTONICALLY INCREASING ABSCISSA ARRAY              SPL00160
C           Y:     ONE-FOR-ONE CORRESPONDING ORDINATE ARRAY             SPL00170
C           M:     NUMBER OF X AND Y VALUES SUPPLIED < OR = 300         SPL00180
C           XINT:  VALUE OF ABSCISSA FOR WHICH CORRESPONDING ORDINATE   SPL00190
C                  IS TO BE INTERPOLATED (OR EXTRAPOLATED)              SPL00200
C           YINT:  INTERPOLATED (OR EXTRAPOLATED) ORDINATE VALUE        SPL00210
C                                                                       SPL00220
C                                                                       SPL00240
C        REMARKS                                                        SPL00250
C           IF SPECIFIED X FALLS OUTSIDE OF RANGE, AN EXTRAPOLATED      SPL00260
C           VALUE WILL BE SUPPLIED                                      SPL00270
C                                                                       SPL00280
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED                  SPL00290
C           SUBROUTINE SPLICO IS INCLUDED IN SUBROUTINE SPLIN PACKAGE   SPL00300
C                                                                       SPL00310
```

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C        MATHEMATICAL METHOD
C           UPON FIRST ENTRY TO SPLIN, A CALL TO SPLICO IS MADE TO
C              DETERMINE THE COEFFICIENTS TO BE USED IN PERFORMING THE
C              INTERPOLATIONS. SEARCH FOR BRACKETING ABSCISSA VALUES IS
C              ALWAYS MADE FROM THE REFERENCE LAST USED IN INTERPOLATING.
C
C        REFERENCE
C              PENNINGTON, RALPH H.,"INTRODUCTORY COMPUTER METHODS AND
C              NUMERICAL ANALYSIS", THE MACMILLAN COMPANY, NEW YORK, 1965
C
C     ------------------------------------------------------------------
C

      SUBROUTINE SPLINE(X,Y,M,XINT,YINT)
      DIMENSION X(M),Y(M),C(4,300)
      CALL SPLICO(X,Y,M,C)
      K=1
      ENTRY SPLINN(X,Y,M,XINT,YINT)
    3 IF(XINT-X(1)) 70,1,2
   70 K=1
      GO TO 7
    1 YINT=Y(1)
      RETURN
    2 IF(XINT-X(K+1))6,4,5
    4 YINT=Y(K+1)
      RETURN
    5 K=K+1
      IF(M-K) 71,71,3
   71 K=M-1
      GO TO 7
    6 IF(XINT-X(K))13,12,11
   12 YINT=Y(K)
      RETURN
   13 K=K-1
      GO TO 6
    7 PRINT 101,XINT
  101 FORMAT(8H0XINT = E18.9,32H, OUT OF RANGE FOR INTERPOLATION)
   11 YINT=(X(K+1)-XINT)*(C(1,K)*(X(K+1)-XINT)**2+C(3,K))
      YINT=YINT+(XINT-X(K))*(C(2,K)*(XINT-X(K))**2+C(4,K))
      RETURN
      END
```

```
      SUBROUTINE SPLICO(X,Y,M,C)                                        SPL00730
      DIMENSION X(M),Y(M),C(4,300),D(300),P(300),E(300),A(300,3),B(300),SPL00750
     1Z(300)                                                            SPL00760
      MM=M-1                                                            SPL00770
      DO 2 K=1,MM                                                       SPL00780
      D(K)=X(K+1)-X(K)                                                  SPL00790
      P(K)=D(K)/6.                                                      SPL00800
    2 E(K)=(Y(K+1)-Y(K))/D(K)                                           SPL00810
      DO 3 K=2,MM                                                       SPL00820
    3 B(K)=E(K)-E(K-1)                                                  SPL00830
      A(1,2)=-1.-D(1)/D(2)                                              SPL00840
      A(1,3)=D(1)/D(2)                                                  SPL00850
      A(2,3)=P(2)-P(1)*A(1,3)                                           SPL00860
      A(2,2)=2.*(P(1)+P(2))-P(1)*A(1,2)                                 SPL00870
      A(2,3)=A(2,3)/A(2,2)                                              SPL00880
      B(2)=B(2)/A(2,2)                                                  SPL00890
      DO 4 K=3,MM                                                       SPL00900
      A(K,2)=2.*(P(K-1)+P(K))-P(K-1)*A(K-1,3)                           SPL00910
      B(K)=B(K)-P(K-1)*B(K-1)                                           SPL00920
      A(K,3)=P(K)/A(K,2)                                                SPL00930
    4 B(K)=B(K)/A(K,2)                                                  SPL00940
      Q=D(M-2)/D(M-1)                                                   SPL00950
      A(M,1)=1.+Q+A(M-2,3)                                              SPL00960
      A(M,2)=-Q-A(M,1)*A(M-1,3)                                         SPL00970
      B(M)=B(M-2)-A(M,1)*B(M-1)                                         SPL00980
      Z(M)=B(M)/A(M,2)                                                  SPL00990
      MN=M-2                                                            SPL01000
      DO 6 I=1,MN                                                       SPL01010
      K=M-I                                                             SPL01020
    6 Z(K)=B(K)-A(K,3)*Z(K+1)                                           SPL01030
      Z(1)=-A(1,2)*Z(2)-A(1,3)*Z(3)                                     SPL01040
      DO 7 K=1,MM                                                       SPL01050
      Q=1./(6.*D(K))                                                    SPL01060
      C(1,K)=Z(K)*Q                                                     SPL01070
      C(2,K)=Z(K+1)*Q                                                   SPL01080
      C(3,K)=Y(K)/D(K)-Z(K)*P(K)                                        SPL01090
    7 C(4,K)=Y(K+1)/D(K)-Z(K+1)*P(K)                                    SPL01100
      RETURN                                                            SPL01110
      END                                                               SPL01120

C000020
C                                                                       MET00010
C         **************************************************************MET00020
C                                                                       MET00030
C         SUBROUTINE MTMPII                                             MET00040
C                                                                       MET00050
C         PURPOSE                                                       MET00060
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```
C              MTMPII WILL PRODUCE,ON THE PRINTER, A CONTOUR MAP       MET00070
C              OF ANY SINGLE PRECISION TWO DIMENSIONAL ARRAY.          MET00080
C                                                                      MET00090
C        USAGE                                                         MET00100
C              CALL MTMPII(Y,N,M,T,BND,AZ,BZ,AMIN,IJT,ICON)            MET00110
C                                                                      MET00120
C        DESCRIPTION OF PARAMETERS                                     MET00130
C                                                                      MET00140
C              Y    - THE ARRAY TO BE CONTOURED. DIMENSIONED Y(N,M)MET00150
C              N    - NUMBER OF ROWS IN Y.                             MET00160
C              M    - NUMBER OF COLUMNS IN Y.                          MET00170
C              T    - ARRAY FOR PLOT TITLE. REAL*4 T(24).              MET00180
C              BND  - BANDWIDTH FOR THE CONTOURING. IF BND IS ZERO MET00190
C                     A BANDWIDTH WILL BE CALCULATED AS FOLLOWS        MET00200
C                     BND=(MAX(Y)-MIN(Y))/15.                          MET00210
C              AZ   - A LINEAR TRANSFORMATION MAYBE PERFORMED ON       MET00220
C                     THE ARRAY Y OF THE FOLLOWING FORM AZ*Y+BZ.       MET00230
C                     IF AZ=0 THEN AZ WILL BE COMPUTED SUCH THAT       MET00240
C                     MAX(|MAX(Y)|,|MIM(Y)|) WILL BE LESS THAN 1,      MET00250
C                     AND BZ WILL BE LEFT AS INPUT.                    MET00260
C              BZ   - SEE UNDER AZ                                     MET00270
C              AMIN - THE LEVEL AT WHICH COUTOURING WILL BEGIN. IF MET00280
C                     AMIN > MIN(Y) THEN AMIN WILL BE CALCULATED       MET00290
C                     TO BE ,WITH REFERENCE AT ZERO, THE NEXT LOWERMET00300
C                     CONTOUR LEVEL FROM MIN(Y) AS DETERMINED BY       MET00310
C                     BND.                                             MET00320
C              IJT  - IF IJT=0 AMIN WILL BE CALCULATED AS DESCRIBEDMET00330
C                     ABOVE.                                           MET00340
C              ICON - IF ICON=0 NO CONTOURING WILL BE DONE BUT THE MET00350
C                     ARRAY Y WILL BE PRINTED IN THE PLOT FORMAT.      MET00360
C                                                                      MET00370
C        REMARKS                                                       MET00380
C              MTMPII REQUIRES A PRINTER WITH 132 PRINT POSITIONS. MET00390
C              IF NECESSARY THE MAP WILL BE SEGMENTED COLUMNWISE.  MET00400
C              THE ROWS AND COLUMNS ARE NUMBERED ALONG THE EDGES SOMET00410
C              THAT A SEGMENTED MAP MAYBE EASILY JOINED TOGETHER.  MET00420
C              ONLY THREE SIGNIFICANT FIGURES WILL BE PRINTED AT   MET00430
C              EACH POINT. THE POSITION OF THE FIRST SIGNIFICANT   MET00440
C              DIGIT WILL BE DETERMINED BY MAX(|MAX(Y)|,|MIN(Y)|). MET00450
C              THE PLOT WILL BE PRODUCED ON A INCH INCH GRID. IT   MET00460
C              WILL BE ASSUMED THAT THE SPACING BETWEEN POINTS IN  MET00470
C              BOTH DIRECTIONS IS THE SAME AND EQUAL FOR ALL POINTSMET00480
C                                                                      MET00490
C        SUBROUTINES REQUIRED                                          MET00500
C              NONE                                                    MET00510
C                                                                      MET00520
C        METHOD                                                        MET00530
C              THE CONTOUR LEVELS ARE DETERMINED BY SIMPLE LINEAR      MET00540
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C                   INTERPOLATION FROM THE FOUR SURROUNDING PIONTS.      MET00550
C                                                                        MET00560
C      ******************************************************************MET00570
C                                                                        MET00580
C                                                                        MET00590
C     MTMPII SUBROUTINE FOR ONE-INCH GRID SPACING                        MET00600
C     OAKES CODE 5105    15 JAN 69                                       MET00610
C                                                                        MET00620

      SUBROUTINE MTMPII(Y,N,M,T,BND,AZ,BZ,AMIN,IJT,ICON)                 MET00630
      REAL*4 IH,KG,ITJZ                                                  MET00640
      DIMENSION A(140),B(140),C(140),D(140),IH(20),Y(N,M),TP(10),TPX(10)MET00650
     Z  ,TPM(10),XMT(10),BTM(10),BTX(10),BT(10),KG(10),T(24)             MET00660
      DIMENSION E(140),F(140),G(140),H(140)                              MET00670
C                                                                        MET00680
C                                                                        MET00690
      DATA DUE/4H    /,EPL/4H+   /,EMI/4H-   /,IH/1H0,1H ,1H1,1H ,1H2,   MET00700
     11H ,1H3,1H ,1H4,1H ,1H5,1H ,1H6,1H ,1H7,1H ,1H8,1H ,1H9,1H /,KG/   MET00710
     21H0,1H1,1H2,1H3,1H4,1H5,1H6.1H7,1H8,1H9/,BLK/4H    /               MET00720
C                                                                        MET00730
      YMIN=Y(1,1)                                                        MET00740
      YMAX=Y(1,1)                                                        MET00750
      DO 20 I=1,M                                                        MET00760
      DO 10 J=1,N                                                        MET00770
      YMIN=AMIN1(YMIN,Y(J,I))                                            MET00780
      YMAX=AMAX1(YMAX,Y(J,I))                                            MET00790
   10 CONTINUE                                                           MET00800
   20 CONTINUE                                                           MET00810
      DELY=YMAX-YMIN                                                     MET00820
      IF(BND) 25,25,30                                                   MET00830
   25 BND=DELY/15.0                                                      MET00840
   30 IF (AMIN-YMIN) 31,31,32                                            MET00850
   31 IF (IJT) 33,32,33                                                  MET00860
   32 PD=YMIN/BND                                                        MET00870
      PF=ABS(PD-INT(PD))                                                 MET00880
      IF (YMIN) 2,1,1                                                    MET00890
    1 AMIN=YMIN-PF*BND                                                   MET00900
      GO TO 33                                                           MET00910
    2 AMIN=YMIN-(1.0-PF)*BND                                             MET00920
   33 AHLD=AZ                                                            MET00930
      IF(AZ) 55,35,55                                                    MET00940
   35 SM=AMAX1(ABS(YMIN),ABS(YMAX))                                      MET00950
      NS=0                                                               MET00960
   40 NS=NS+1                                                            MET00970
      SM=10.0*SM                                                         MET00980
      IF(SM-1.0)40,50,45                                                 MET00990
   45 NS=NS-1                                                            MET01000
```

```
      SM=SM/10.0                                                        METO1010
      IF(SM-1.0)50,50,45                                                METO1020
   50 AHLD=10.0**NS                                                     METO1030
   55 HBND=BND/2.0                                                      METO1040
      PRINT 70                                                          METO1050
      PRINT 6,T                                                         METO1060
    6 FORMAT(5X,24A4,//)                                                METO1070
      PRINT 57,AHLD,BZ                                                  METO1080
   57 FORMAT(1H0,65HTHE FOLLOWING TRANSFORMATION WAS PERFORMED ON THE INMETO1090
     1PUT MATRIX     /5X,1H(,E12.5,8H*Y(I,J)+,E12.5,1H) //2X,73HAND THREEMETO1100
     2 DIGITS TO THE RIGHT OF THE DECIMAL POINT ARE PRINTED IN THE MAP )METO1110
C                                                                       METO1120
      PRINT 54,YMAX,YMIN                                                METO1130
   54 FORMAT(/4X,5HYMAX=,E15.7,5X,5HYMIN=,E15.7)                        METO1140
      IF (ICON)5,58,5                                                   METO1150
    5 PRINT 11,BND                                                      METO1160
   11 FORMAT(2X,17HTHE BAND WIDTH IS,E12.5,6H UNITS //4X,14HCONTOUR LEVEMETO1170
     1LS        )                                                       METO1180
      I=0                                                               METO1190
      YTOP=AMIN                                                         METO1200
      IF(ABS(YMIN-YMAX)-100.0*BND)53,53,58                              METO1210
   53 YB=YTOP                                                           METO1220
      YTOP=YTOP+BND                                                     METO1230
      I=I+1                                                             METO1240
      J=MOD(I,20)                                                       METO1250
      ITJZ=IH(J)                                                        METO1260
      IF(YB-YMAX)59,58,58                                               METO1270
   59 PRINT 61,YB,YTOP,ITJZ                                             METO1280
   61 FORMAT(/4X,E10.3,4H TO ,E10.3,2H =,1X,A1)                         METO1290
      GO TO 53                                                          METO1300
   58 NCCP=0                                                            METO1310
      NCP=0                                                             METO1320
   60 PRINT 70                                                          METO1330
   70 FORMAT(1H1)                                                       METO1340
      PRINT 6,T                                                         METO1350
      NLINE=0                                                           METO1360
      NCCP=NCP+1                                                        METO1370
      NCP = NCP + 13                                                    METO1380
   73 IF(NCP-M)80,80,75                                                 METO1390
   75 NCP=M                                                             METO1400
   80 CONTINUE                                                          METO1410
      J=-2                                                              METO1420
      NLINE=NLINE+1                                                     METO1430
      LLINE=N-NLINE+1                                                   METO1440
C SET UP HEADING                                                        METO1450
      IF(NCCP-1) 85,85,90                                               METO1460
   85 J = - 1                                                           METO1470
   90 DO 100 I = 1,135                                                  METO1480
```

```
      A(I)=BLK                                                          METO1490
      B(I)=BLK                                                          METO1500
      H(I) = BLK                                                        METO1510
  100 CONTINUE                                                          METO1520
  110 DO 160 L=NCCP,NCP                                                 METO1530
      J = J+8                                                           METO1540
      KI=L                                                              METO1550
      IF(KI-100) 130,120,120                                            METO1560
  120 LL=KI/100                                                         METO1570
      A(J)=KG(LL+1)                                                     METO1580
      KI=KI-100*LL                                                      METO1590
      GO TO 135                                                         METO1600
  130 A(J)=KG(1)                                                        METO1610
  135 J=J+1                                                             METO1620
      IF(KI-10) 150,140,140                                             METO1630
  140 LL=KI/10                                                          METO1640
      A(J)=KG(LL+1)                                                     METO1650
      KI=KI-10*LL                                                       METO1660
      GO TO 155                                                         METO1670
  150 A(J)=KG(1)                                                        METO1680
  155 J=J+1                                                             METO1690
      A(J)=KG(KI+1)                                                     METO1700
  160 CONTINUE                                                          METO1710
C SETUP FIRST ROW OF ARRAY                                              METO1720
      GO TO 260                                                         METO1730
  170 NLINE=NLINE+1                                                     METO1740
      LLINE=N-NLINE+1                                                   METO1750
      IF(NLINE-N) 180,180,380                                           METO1760
  180 DO 190 I=1,135                                                    METO1770
      A(I)=BLK                                                          METO1780
      B(I)=BLK                                                          METO1790
      C(I)=BLK                                                          METO1800
      D(I)=BLK                                                          METO1810
      E(I) = BLK                                                        METO1820
      F(I) = BLK                                                        METO1830
      G(I) = BLK                                                        METO1840
      H(I) = BLK                                                        METO1850
  190 CONTINUE                                                          METO1860
      IF (ICON)195,260,195                                              METO1870
  195 NCY=NCCP-1                                                        METO1880
      J=4                                                               METO1890
      IF(NCY)200,200,210                                                METO1900
  200 J=5                                                               METO1910
  210 NCY=NCY+1                                                         METO1920
      IF(NCY-NCP) 220,220,260                                           METO1930
  220 IF(NCY-M) 230,260,260                                             METO1940
  230 NLINE = NLINE - 1                                                 METO1950
      YD1 = Y(NLINE,NCY) - Y(NLINE+1,NCY)                               METO1960
```

```
      YD2=Y(NLINE,NCY+1)-Y(NLINE+1,NCY+1)                              MET01970
      TP(1) = Y(NLINE,NCY)-0.125*YD1                                   MET01980
      TPX(1)=Y(NLINE,NCY)-0.250*YD1                                    MET01990
      TPM(1)=Y(NLINE,NCY)-0.375*YD1                                    MET02000
      XMT(1)=Y(NLINE,NCY)-0.500*YD1                                    MET02010
      BTM(1)=Y(NLINE,NCY)-0.625*YD1                                    MET02020
      BTX(1)=Y(NLINE,NCY)-0.750*YD1                                    MET02030
      BT (1)=Y(NLINE,NCY)-0.875*YD1                                    MET02040
      TP (10)=Y(NLINE,NCY+1)-0.125*YD2                                 MET02050
      TPX(10)=Y(NLINE,NCY+1)-0.250*YD2                                 MET02060
      TPM(10)=Y(NLINE,NCY+1)-0.375*YD2                                 MET02070
      XMT(10)=Y(NLINE,NCY+1)-0.500*YD2                                 MET02080
      BTM(10)=Y(NLINE,NCY+1)-0.625*YD2                                 MET02090
      BTX(10)=Y(NLINE,NCY+1)-0.750*YD2                                 MET02100
      BT (10)=Y(NLINE,NCY+1)-0.875*YD2                                 MET02110
      NLINE = NLINE + 1                                                MET02120
      D1=0.1 * (TP (10)-TP (1))                                        MET02130
      D2=0.1 * (TPX(10)-TPX(1))                                        MET02140
      D3=0.1 * (TPM(10)-TPM(1))                                        MET02150
      D4=0.1 * (XMT(10)-XMT(1))                                        MET02160
      D5=0.1 * (BTM(10)-BTM(1))                                        MET02170
      D6=0.1 * (BTX(10)-BTX(1))                                        MET02180
      D7=0.1 * (BT (10)-BT (1))                                        MET02190
      DO 240 I = 2,9                                                   MET02200
      TP (I)=TP (I-1)+D1                                               MET02210
      TPX(I)=TPX(I-1)+D2                                               MET02220
      TPM(I)=TPM(I-1)+D3                                               MET02230
      XMT(I)=XMT(I-1)+D4                                               MET02240
      BTM(I)=BTM(I-1)+D5                                               MET02250
      BTX(I)=BTX(I-1)+D6                                               MET02260
      BT (I)=BT (I-1)+D7                                               MET02270
  240 CONTINUE                                                         MET02280
      DO 250 I=1,10                                                    MET02290
      J=J+1                                                            MET02300
      I1=MOD(IFIX((TP (I)-AMIN)/BND),20)+1                             MET02310
      I2=MOD(IFIX((TPX(I)-AMIN)/BND),20)+1                             MET02320
      I3=MOD(IFIX((TPM(I)-AMIN)/BND),20)+1                             MET02330
      I4=MOD(IFIX((XMT(I)-AMIN)/BND),20)+1                             MET02340
      I5=MOD(IFIX((BTM(I)-AMIN)/BND),20)+1                             MET02350
      I6=MOD(IFIX((BTX(I)-AMIN)/BND),20)+1                             MET02360
      I7=MOD(IFIX((BT (I)-AMIN)/BND),20)+1                             MET02370
      A(J)=IH(I1)                                                      MET02380
      B(J)=IH(I2)                                                      MET02390
      C(J)=IH(I3)                                                      MET02400
      D(J)=IH(I4)                                                      MET02410
      E(J)=IH(I5)                                                      MET02420
      F(J)=IH(I6)                                                      MET02430
      G(J)=IH(I7)                                                      MET02440
```

```
  250 CONTINUE                                                          METO2450
      GO TO 210                                                         METO2460
  260 NCY=NCCP-1                                                        METO2470
      J=-2                                                              METO2480
      IF(NCY) 265,265,270                                               METO2490
  265 J=-1                                                              METO2500
      GO TO 330                                                         METO2510
  270 NCY=NCY+1                                                         METO2520
      IF(NCY-NCP) 280,280,310                                           METO2530
  280 J=J+7                                                             METO2540
      THLD=AHLD*Y(NLINE,NCY)+BZ                                         METO2550
      IF(THLD) 285,290,290                                              METO2560
  285 H(J)=EMI                                                          METO2570
      GO TO 295                                                         METO2580
  290 H(J)=EPL                                                          METO2590
  295 NUM=INT(ABS(THLD-INT(THLD))*1000.0+0.5)                           METO2600
      NDS=100                                                           METO2610
      DO 300 KK=1,3                                                     METO2620
      J=J+1                                                             METO2630
      KI=NUM/NDS                                                        METO2640
      H(J)=KG(KI+1)                                                     METO2650
      NUM=NUM-KI*NDS                                                    METO2660
      NDS=NDS/10                                                        METO2670
  300 CONTINUE                                                          METO2680
      GO TO 270                                                         METO2690
  310 IF(NCP-M) 360,320,320                                             METO2700
  320 IF(J-127)330,330,360                                              METO2710
  330 J=J+3                                                             METO2720
      KI=NLINE                                                          METO2730
      IF(KI-100) 340,335,335                                            METO2740
  335 LL=KI/100                                                         METO2750
      H(J)=KG(LL+1)                                                     METO2760
      KI=KI-100*LL                                                      METO2770
      GO TO 343                                                         METO2780
  340 H(J)=KG(1)                                                        METO2790
  343 J=J+1                                                             METO2800
      IF(KI-10) 350,345,345                                             METO2810
  345 LL=KI/10                                                          METO2820
      H(J)=KG(LL+1)                                                     METO2830
      KI=KI-10*LL                                                       METO2840
      GO TO 355                                                         METO2850
  350 H(J)=KG(1)                                                        METO2860
  355 J=J+1                                                             METO2870
      H(J)=KG(KI+1)                                                     METO2880
      J=J-5                                                             METO2890
      IF(NCY-1) 270,270,360                                             METO2900
  360 IF(NLINE-1)362,362,368                                            METO2910
  362 PRINT 370,(A(I),I=1,132),(B(IP1),IP1=1,132),(H(IP2),IP2=1,132)    METO2920
```

```
      GO TO 170                                                         MET02930
  368 PRINT 370,(A(I),I=1,132),(B(IP1),IP1=1,132),(C(IP2),IP2=1,132),   MET02940
     1(D(IP3),IP3=1,132),(E(IP4),IP4=1,132),(F(IP5),IP5=1,132),         MET02950
     2(G(IP6),IP6=1,132),(H(IP7),IP7=1,132)                             MET02960
  370 FORMAT(132A1)                                                     MET02970
      GO TO 170                                                         MET02980
  380 DO 390 I=1,135                                                    MET02990
      A(I)=BLK                                                          MET03000
      B(I)=BLK                                                          MET03010
      C(I)=BLK                                                          MET03020
      D(I)=BLK                                                          MET03030
  390 CONTINUE                                                          MET03040
      J=-2                                                              MET03050
      IF(NCCP-1) 395,395,400                                            MET03060
  395 J=-1                                                              MET03070
  400 DO 430 L=NCCP,NCP                                                 MET03080
      J=J+8                                                             MET03090
      KI=L                                                              MET03100
      IF(KI-100) 410,405,405                                            MET03110
  405 LL=KI/100                                                         MET03120
      C(J)=KG(LL+1)                                                     MET03130
      KI=KI-100*LL                                                      MET03140
      GO TO 412                                                         MET03150
  410 C(J)=KG(1)                                                        MET03160
  412 J=J+1                                                             MET03170
      IF(KI-10) 420,415,415                                             MET03180
  415 LL=KI/10
      C(J)=KG(LL+1)                                                     MET03200
      KI=KI-10*LL                                                       MET03210
      GO TO 422                                                         MET03220
  420 C(J)=KG(1)                                                        MET03230
  422 J=J+1                                                             MET03240
      C(J)=KG(KI+1)                                                     MET03250
  430 CONTINUE                                                          MET03260
      PRINT 370, (B(IP1),IP1=1,132),(C(IP2),IP2=1,132)                  MET03270
      IF(NCP-M)60,500,500                                               MET03280
  500 RETURN                                                            MET03290
      END                                                               MET03300

C000021
C                                                                       GAUS  10
C     ..................................................................GAUS  20
C                                                                       GAUS  30
C        SUBROUTINE GAUSS                                               GAUS  40
C                                                                       GAUS  50
C        PURPOSE                                                        GAUS  60
C           COMPUTES A NORMALLY DISTRIBUTED RANDOM NUMBER WITH A GIVEN  GAUS  70
```

```
C           MEAN AND STANDARD DEVIATION
C
C        USAGE
C           CALL GAUSS(IX,S,AM,V)
C
C        DESCRIPTION OF PARAMETERS
C           IX -IX MUST CONTAIN AN ODD INTEGER NUMBER WITH NINE OR
C               LESS DIGITS ON THE FIRST ENTRY TO GAUSS. THEREAFTER
C               IT WILL CONTAIN A UNIFORMLY DISTRIBUTED INTEGER RANDOM
C               NUMBER GENERATED BY THE SUBROUTINE FOR USE ON THE NEXT
C               ENTRY TO THE SUBROUTINE.
C           S  -THE DESIRED STANDARD DEVIATION OF THE NORMAL
C               DISTRIBUTION.
C           AM -THE DESIRED MEAN OF THE NORMAL DISTRIBUTION
C           V  -THE VALUE OF THE COMPUTED NORMAL RANDOM VARIABLE
C
C        REMARKS
C           THIS SUBROUTINE USES RANDU WHICH IS MACHINE SPECIFIC
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           RANDU
C
C        METHOD
C           USES 12 UNIFORM RANDOM NUMBERS TO COMPUTE NORMAL RANDOM
C           NUMBERS BY CENTRAL LIMIT THEOREM. THE RESULT IS THEN
C           ADJUSTED TO MATCH THE GIVEN MEAN AND STANDARD DEVIATION.
C           THE UNIFORM RANDOM NUMBERS COMPUTED WITHIN THE SUBROUTINE
C           ARE FOUND BY THE POWER RESIDUE METHOD.
C
C     ..................................................................
C

      SUBROUTINE GAUSS(IX,S,AM,V)
      A=0.0
      DO 50 I=1,12
      CALL RANDU(IX,IY,Y)
      IX=IY
   50 A=A+Y
      V=(A-6.0)*S+AM
      RETURN
      END

C000022
C
C     ..................................................................
C
```

```
C
C        SUBROUTINE RANDU
C
C        PURPOSE
C           COMPUTES UNIFORMLY DISTRIBUTED RANDOM REAL NUMBERS BETWEEN
C           0 AND 1.0 AND RANDOM INTEGERS BETWEEN ZERO AND
C           2**31. EACH ENTRY USES AS INPUT AN INTEGER RANDOM NUMBER
C           AND PRODUCES A NEW INTEGER AND REAL RANDOM NUMBER.
C
C        USAGE
C           CALL RANDU(IX,IY,YFL)
C
C        DESCRIPTION OF PARAMETERS
C           IX - FOR THE FIRST ENTRY THIS MUST CONTAIN ANY ODD INTEGER
C                NUMBER WITH NINE OR LESS DIGITS. AFTER THE FIRST ENTRY,
C                IX SHOULD BE THE PREVIOUS VALUE OF IY COMPUTED BY THIS
C                SUBROUTINE.
C           IY - A RESULTANT INTEGER RANDOM NUMBER REQUIRED FOR THE NEXT
C                ENTRY TO THIS SUBROUTINE. THE RANGE OF THIS NUMBER IS
C                BETWEEN ZERO AND 2**31
C           YFL- THE RESULTANT UNIFORMLY DISTRIBUTED, FLOATING POINT,
C                RANDOM NUMBER IN THE RANGE 0 TO 1.0
C
C        REMARKS
C           THIS SUBROUTINE IS SPECIFIC TO SYSTEM/360 AND WILL PRODUCE
C           2**29 TERMS BEFORE REPEATING.  THE REFERENCE BELOW DISCUSSES
C           SEEDS (65539 HERE), RUN PROBLEMS, AND PROBLEMS CONCERNING
C           RANDOM DIGITS USING THIS GENERATION SCHEME.  MACLAREN AND
C           MARSAGLIA, JACM 12, P. 83-89, DISCUSS CONGRUENTIAL
C           GENERATION METHODS AND TESTS.  THE USE OF TWO GENERATORS OF
C           THE RANDU TYPE, ONE FILLING A TABLE AND ONE PICKING FROM THE
C           TABLE, IS OF BENEFIT IN SOME CASES.  65549 HAS BEEN
C           SUGGESTED AS A SEED WHICH HAS BETTER STATISTICAL PROPERTIES
C           FOR HIGH ORDER BITS OF THE GENERATED DEVIATE.
C           SEEDS SHOULD BE CHOSEN IN ACCORDANCE WITH THE DISCUSSION
C           GIVEN IN THE REFERENCE BELOW.  ALSO, IT SHOULD BE NOTED THAT
C           IF FLOATING POINT RANDOM NUMBERS ARE DESIRED,AS ARE
C           AVAILABLE FROM RANDU, THE RANDOM CHARACTERISTICS OF THE
C           FLOATING POINT DEVIATES ARE MODIFIED AND IN FACT THESE
C           DEVIATES HAVE HIGH PROBABILITY OF HAVING A TRAILING LOW
C           ORDER ZERO BIT IN THEIR FRACTIONAL PART.
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           POWER RESIDUE METHOD DISCUSSED IN IBM MANUAL C20-8011,
C           RANDOM NUMBER GENERATION AND TESTING
C
```

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C     ..................................................................
C

      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

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